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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

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THE

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REPORT OF THE COMMITTEE ON STELLAR CLASSIFICATION ADOPTED BY THE INTERNATIONAL ASTRONOMICAL UNION AT THE MEETING AT ROME, MAY 10, 1922[1]

The Committee[2] on Classification of Stellar Spectra finds its work greatly simplified by the fact that a definite plan of classification—the Harvard System—has already been adopted by international agreement, and has been used in extensive works, such as the *Henry Draper Catalogue*, which will be of value for a long time. Its duty, therefore, is not to make radical alterations in this system, such as changing the significance of the existing letters, or substituting numbers for them, but to suggest such modifications and extensions of the existing notation as may increase its usefulness to students of astrophysics.

a) With increasing knowledge of stellar spectra, it is desirable to have additional symbols which may be used to designate many of those characteristics which were formerly dismissed as "peculiarities." The new notation may in some cases appear complicated, but it should be remembered that its use is permissive, and not mandatory. The older notation remains complete in itself, and for many purposes is all that

[1] Reprinted, by permission, from *Transactions of the International Astronomical Union*, 1, 1922. London: Imperial College Bookstall, S.W. 7. Pp. 247+viii. Price, 15 shillings.

[2] The committee consisted of W. S. Adams, chairman, Miss Annie J. Cannon, Messrs. R. H. Curtiss, A. Fowler, A. de Gramont, M. Hamy, H. F. Newall, J. S. Plaskett, and H. N. Russell. Messrs. N. Bohr and M. N. Saha were added to the committee.

will be required, while the new makes it possible to compress into small compass information which would otherwise require voluminous notes.

b) The additional distinctions, like the original classification, are based on the line and band absorption and emission. The distribution of intensity on the continuous background is of great importance; but it is not considered, for three reasons: (1) It is already known that the correlation between the intensity distribution and the spectral class is so far from perfect that two practically independent symbols are required to express them. (2) All instruments record the line-spectrum in substantially the same fashion—barring the effects of different dispersion and resolving power. This is not the case for the intensity of the background, which may be influenced by such factors as absorption in the prisms. Great care is, therefore, necessary in interpreting the results obtained from spectrograms. (3) This distribution is intimately related to the color index and to the energy distribution in the spectrum. The problem involves spectroscopy, photometry, and the measurement of heat radiation.

c) It is evidently ultimately desirable that each spectral class should be precisely defined, both by verbal description and by means of standard stars. The present moment, however, does not appear opportune for doing more in this way than has already been done at Harvard. The exact relation of some of the more unusual classes of spectra remain to be investigated. Moreover, the recent application of the theory of ionization to stellar spectra promises a greater insight into the physical meaning of the spectral lines. There is good reason to believe that the relative intensities of lines emitted by the neutral atoms depend almost exclusively upon the temperature, while the intensities of enhanced lines, relative to those of the former groups, will vary also with the pressure or density of the star's atmosphere. It seems, therefore, desirable to postpone the *precise* definition of the characteristics of each spectral class until the relations of these two types of lines to the temperatures and absolute magnitudes of the star have been further considered.

I. GUIDING PRINCIPLES

a) The classification should describe the *spectra*, not the stars; that is, it should be based solely on what can be seen in the spectrum of a given star, when observed at a suitable time and with appropriate instruments.

b) The Draper Classification, or "Harvard System," which has already been adopted internationally, should be the basis on which any

further extensions should be built. Classification on other and different systems should be abandoned permanently.

c) Designations at present forming part of the Draper Classification should either be retained with the old meaning or abandoned entirely. No attempt should be made to retain the symbol but alter the meaning.

d) The capital letters, B, A, F, etc., *standing alone*, should be used to describe a spectrum only in those cases, when, on account of poor photographs or for other reasons, nothing more than the general character of the spectrum can be determined.

Similarly B–A, K–M may denote spectra which lie somewhere between the classes mentioned when more precise specifications cannot be made.

e) In cases of great uncertainty, Secchi's types may be employed. These may be characterized briefly as follows:

		Harvard Types
Type I.	Predominant hydrogen lines	Oe, B, A, F, F5
Type II.	Prominent metallic lines	F8, G, K, K5
Type III.	Titanium oxide bands	M
Type IV.	Carbon bands	N, R
Type V.	Bright Wolf-Rayet lines	Oa, Ob, Oc, Od

It is not recommended that this grouping be used in statistical work on account of the extreme heterogeneity of Type I. Stars of spectra Oe to B5 should, in any case, be separated from the other stars of Type I.

f) The decimal system of classification (G2, etc.) should be used in all cases in which it is established that a continuous spectral sequence exists. Such combinations will hereafter be called the "main symbol."

g) The present notation by means of small letters appended to the capital letter (as Oa) should be retained in cases in which it has not been clearly established that a continuous and unique sequence exists.

h) The terms "early" and "late" are very convenient. It is well, however, to emphasize that they denote positions early or late in the spectral sequence O—B—A—F—G—K—M, without any necessary connection whatever with an early or late stage of physical evolution. The terms "hotter" and "cooler," "whiter" or "redder" sometimes cover the same characteristics, but describe the star rather than the spectrum.

i) Composite spectra should be denoted by the sign + connecting the two superposed types (as K0+B9), or by two separate lines as is done in the *Henry Draper Catalogue.* The latter is convenient for purposes of tabulation.

j) The spectra of variable stars should normally be recorded as at maximum brightness. When the spectrum varies continuously, as in Cepheid variables, it may be recorded, for example, as F7 to G4; when discontinuously as in eclipsing variables, like a composite spectrum, e.g., Ao+K or $\left\{\begin{matrix}\text{Ao}\\ \text{K}\end{matrix}\right.$

k) Additional notation should be devised to describe as many as may be convenient of those spectral characteristics which are known to be common to any considerable number of stars. Such notations should be simple to print, and convey as much information as may be practicable in a small compass.

II. SPECIFIC EXAMPLES OF THESE RULES

I.*c*. Although the evidence of color index suggests strongly that what is now called K5 is really much nearer to M than to K, it is inadmissible to change the designation of this type to K8. The meaning of the symbols in the existing catalogues must be preserved.

Again, the notation Md has been found to include cases in which the "underlying spectrum" is not of Class M at all. This symbol may, therefore, advantageously be dropped.

I.*f*. and *g*. (i) Although the evidence is strong that Oe and Oe5 represent spectra immediately preceding Bo, the spectral sequence in Classes Oa to Od is not yet certainly worked out. Hence it seems desirable to retain for the present the existing notation for all these classes.

(ii) Again, Ma, Mb, and Mc clearly form a sequence, running on continuously from K5. It is suggested that they be called in future Mo, M3, and M8, the second interval on the decimal classification being taken wider than the other, because it appears to correspond to a greater difference in the spectra.

(iii) Similarly, Na and Nb may be called in future No and N3. The relations of the very red stars called Nc by Miss Cannon are not yet clear enough to justify giving their spectra a decimal notation.

Spectra intermediate between K and R (should such occur) will have to be called K5R.

(iv) The question of the notation for the spectra of gaseous nebulae should be deferred until further investigations have been made. Attention should be called, however, to the strong desirability of classifying the spectra of the nebula and the nucleus separately whenever possible.

III. NEW SPECTRAL CLASSES

a) Novae

It seems very desirable to have some less cumbersome description than at present of the successive stages through which the spectrum of a Nova ordinarily passes. The letter Q has been used for spectra of this type (*Harvard Annals*, **28**) and should be retained. In view of the uncertainties of progression in sequence, the differences between various novae and the intermingling of spectral characteristics, the decimal notation cannot at present be used. The following quite provisional system of notation is suggested, not for immediate use, but as a basis of discussion, in the anticipation that it will be revised and improved in the future. The use of the letter "e" to indicate the presence of bright lines in other classes of spectra precludes its use in this connection. Bright bands due to hydrogen appear always to be present, except in Class Qz, and are not referred to specifically.

Qa Absorption spectrum of faint lines. Bright bands inconspicuous.

Qb Absorption spectrum of stronger lines, mainly enhanced metallic, many of which are double. Bright bands stronger.

Qc Absorption spectrum of enhanced lines, oxygen, nitrogen, helium and associated elements. Bright lines of all of these elements.

Qu Broad nebulous emission bands near 3480, 4515, and 4640A, accompanied at times by one at 4379A. The spectrum appears usually to occur in conjunction with other typical forms which it may modify through the extinction of some of their characteristic radiations, particularly 3445 and 4686A.

Qx Bright bands due to enhanced lines, oxygen, nitrogen, and helium. Absorption lines faint.

Qy Bright nebular bands in addition to preceding.

Qz Bright nebular bands. Weak Wolf-Rayet bands.

The stage in which Wolf-Rayet bands are strong in addition to the nebular bands may be indicated by Qz5O. (Capital letter O.)

Combinations of any of these spectra may be indicated by combinations of the letters. Thus Qbc would indicate that spectrum Qb was more prominent than Qc, and Qcb would show the reverse.

b) A New Class of Red Stars

Miss Cannon has found that a number of long-period variables and some other red stars, such as π_1 Gruis, R Cygni, and R Andromedae, have underlying spectra which are similar to one another, but do not

resemble Class M, and Dr. Merrill has shown from slit spectrograms that they do not resemble Classes R or N. Their spectrum in the region λ 4500 to λ 4700 is of a most complicated nature, and appears to consist of both absorption and emission lines, with absorption bands present at about λ 4650 and λ 6470. Most of the stars belonging to this type are long-period variables, and show bright hydrogen lines. The type may represent a third branch of the main spectral sequence, cognate with the K5-M and R-N branches. The letter S is suggested for this type.

IV. NOTATION FOR PECULIARITIES

a) Characteristics Connected with Absolute Magnitude

When observations of sufficient delicacy have been made, the spectroscopic absolute magnitude, upon the Mount Wilson system, provides a detailed description of these peculiarities. The more conspicuous differences, however, which can be detected upon inspection by an observer once familiar with them, suffice to divide the spectra into three groups. These may be denoted by small letters placed before the main symbol. They are defined as follows:

1. *Very Bright Stars*

All lines normally are narrow and sharp. In spectra later than Ao, the hydrogen lines are abnormally strong for the general spectral type. So also are the enhanced lines. λ 4227 *Ca* is abnormally weak compared with Hγ or λ 4215 *Sr*+.[1]

This set of characteristics, which is very conspicuous, is shown by Miss Maury's "c-stars," by the Cepheid variables, the stars called "pseudo-Cepheids" by Adams and Joy, and by practically all other stars of exceptionally great luminosity including some cases, like ζ^1 Scorpii and β Orionis, of type B.

It is suggested that these be denoted by the prefix *c* and be called "c-stars," leaving the term Cepheids for variables.

2. *Bright Stars*

In these spectra the enhanced lines are fairly strong. λ 4227 has a moderate intensity for the spectral type. The low-temperature lines, such as $\lambda\lambda$ 4435 *Ca*, and 4454 *Ca*, are relatively weak. The hydrogen lines are strong.

In class F, $\lambda\lambda$ 4077 *Sr*+, 4215 *Sr*+, 4290 *Ti*+ are strong.

[1] The sign "+" following a chemical symbol indicates that the line in question is an enhanced line, originating in ionized (positively charged) atoms.

In classes G, K, and M, λλ 4077 and 4215 are strong.

These are ordinary giant stars, and their spectra may be denoted by the prefix *g*.

3. *Faint Stars*

In these spectra λ 4227 is strong for the class, and λλ 4435, 4454 *Ca* and 4535 *Ti* are strong. The enhanced lines are weak.

In Class F, λλ 4077, 4215 and 4290 are weak.

In Class M, λ 4607 *Sr* is relatively strong, the hydrogen lines are weak.

These spectra may be denoted by the prefix *d* (dwarf stars).

For spectra earlier than Bo these differences disappear, so far as is known, all the stars being bright. The difference between ordinary giant and dwarf stars does not become prominent until spectra later than Fo are reached. The prefix *c*, therefore, will not at present be used with spectra earlier than Bo, or *g* and *d* with spectra earlier than Fo.

In the selection of standard or typical spectra, it is recommended that the fundamental types shall be giant stars, preferably of absolute magnitude about o or +1 (except in Class B, where they must necessarily be brighter). Stars showing either the c-star or dwarf characteristics should be selected as auxiliary standards.

There is additional reason for this, because in the classification of the spectra of dwarf stars developed at Mount Wilson, the decimal subdivisions are of much less unequal value than in the Harvard classification for giant stars. A dwarf K5 is much more nearly midway between Ko and Mo than a giant K5. It may be remarked incidentally that in plotting the physical data, it is well to plot K2 and K5 for giant stars as if they were K5 and K8, respectively. This should not, however, be done in the case of the dwarfs.

b) WIDTH OF LINES

Exceptionally narrow lines usually appear to be associated with the "c" peculiarity, and are already accounted for. Spectra showing all the lines unusually wide or diffuse on good plates may be denoted by "n," following Rowland's designation for diffuse (nebulous) lines in the solar spectrum. Similarly the letter "s" may be used to qualify spectra in which the lines are sharp, but in which the "c" characteristics (such as abnormally strong hydrogen and enhanced lines) are not present.

c) DOUBLE LINES

Spectra in which the lines are double rather than reversed belong to spectroscopic binaries with both components bright. In such cases the notation for composite spectra should be used.

The spectra of spectroscopic binaries in which only one component is visible present, as such, no peculiarity. Variable radial velocity cannot be detected by mere inspection of a single spectrum. They should not receive any special notation.

d) Stationary Lines

On the other hand so-called "stationary" (H) and (K) lines (so far found only in types O and B) are recognizable by their appearance, being very much sharper than the other lines in the spectrum. The symbol "k" suggesting the (K) line is proposed for this class of stars. The same symbol may be used to describe spectra in which the (D) lines and possibly others show the same characteristics. To illustrate, δ Orionis would be designated Bonk.

e) Bright Lines

It is suggested that spectra showing bright lines be denoted by the letter "e" (emission), except in classes where bright lines are normally present (as in O, P, and Q).[1]

In certain classes, most of the bright line stars have fairly definite characteristics, and may be considered as forming a recognized group. In these spectral classes, a spectrum which has emission lines differing considerably from those of the recognized group may be denoted by "ep." Cases in which the bright lines are conspicuously "reversed" (with a dark center) may be denoted by "er." These recognized groups are as follows:

1. *Classes A and B*

The hydrogen series may be thought of as composed of the normal Class B absorption lines, increasing in strength from Hα toward the violet, each having superposed upon it, in a nearly symmetrical position, one of a series of bright lines which decrease in strength from Hα toward the violet. Frequently in the hydrogen series (with a one-prism slit-spectrograph) one or more of the lines Hβ to Hϵ will show *both* emission and absorption components, the lines toward the violet showing no emission, and those toward the red showing no absorption; but in some cases Hα is the only distinct emission line. The emission lines often are double, and in some cases may appear as bright edges to a well-defined absorption line. Fainter emission lines (enhanced metallic) may or may not be present.

[1] The notation Pe, already in use, is still admissible, as it denotes a type of bright line spectrum.

Slight lack of symmetry of the combined bright and dark hydrogen lines need not require the suffix "p."

If desired, the letters α, β, etc., may be appended to indicate which is the last visible bright line of the hydrogen series.

In certain stars, such as P Cygni, the lines consist of a bright emission line with an absorption line bounding it on the violet side. These spectra may be denoted by "eq," the "q" recalling their similarity to certain stages of the spectra of Novae.

2. *Classes M, N, R, and S*

In all these the bright lines are usually of the type associated with long-period variability. The hydrogen lines are bright and narrow, with no absorption components visible. In Class M, $H\gamma$ is usually bright and conspicuous, while $H\delta$ is still stronger. $H\epsilon$ is absent or extremely weak, $H\beta$ and $H\alpha$ are weak or absent, except when the underlying spectrum is of an early division of Class M, or possibly a late one of Class K, in which case $H\beta$, $H\gamma$, and $H\delta$ may have approximately equal intensities. Weaker bright lines, especially at $\lambda\lambda$ 3905, 4138, 4178, and 4202, are not unusual. In stars of Class S, which show bright hydrogen lines, $H\beta$ is much stronger than $H\gamma$ or $H\delta$, though $H\gamma$ is usually conspicuous.

As these differences in the intensity of the hydrogen lines appear to be closely correlated with the underlying spectrum, no additional notation to describe them appears to be called for at present.

Consideration of a notation for the spectra of long-period variables near minimum should be deferred till they have been more fully investigated. It is already known that in *o* Ceti at least, the spectrum at minimum is very different from that at maximum, or from any other known spectrum.

3. *Classes F, G, and K*

Bright line spectra are here so rare that no characteristic group can be recognized. The mere addition of the suffix "e" may serve for the few known cases, which are far from similar to one another.

f) Variable Spectra

In certain cases the spectrum of a star varies. Although this is a peculiarity of the star and not of the spectrum, it is obviously desirable to refer to it in catalogues of spectra. This may be done either by giving the limiting types between which the spectrum varies, as for example, cF5–cG2, or simply by annexing the letter "v" to the spectral designa-

tion. The symbol "ev" will denote variability in emission lines such as has been observed in many B-type stars. In such cases, as in those in which the letter "p" is used, details should be given in notes.

g) Other Peculiarities

The letter "p" should be used to denote miscellaneous peculiarities, not sufficiently frequent or important to justify individual designations. It may be suggested that this should be understood to qualify the symbol immediately preceding. Thus B2pe would denote a star of Class B2, with peculiarities in the absorption spectrum, and emission lines of the normal type, while B2ep would denote a star with peculiar emission lines.

Similarly, A2pn would denote a peculiar A2 spectrum in which all the lines were wide; A2np one in which the lines were widened in some peculiar fashion.

The same principle may be extended to other symbols. Thus F8ne would denote an F8 spectrum with all lines wide, and with bright lines; F8en, one in which the dark lines were normal, but the bright lines abnormally wide.

V. NOTATION OF INDIVIDUAL LINES

a) The Fraunhofer letters for certain lines are so well established that it does not seem desirable to abandon them. Following a suggestion of the Committee on Notations, these lines should be denoted by letters in brackets or parentheses. Those symbols which it is proposed to preserve are (A), (a), (B), (α), (D), (b), (G), (H), and (K). It is worthy of note that each of these with the exception of the last two, denotes a group of lines having a common origin. Since the lines of the (E) group do not all belong to the same element, there is no reason for retaining this symbol.

For the hydrogen lines, the notation $H\alpha$, $H\beta$, etc., should be adopted.

d) In giving the origin of a line, the chemical symbol of the element should be printed in italics, as recommended by the Committee on Notations. When the line is known to originate in an ionized atom, or shows other strong evidence of being an enhanced line, the chemical symbol should be followed by the sign +, in accordance with the usage now prevailing among physicists. Thus λ 4571 *Mg*, λ 4481 *Mg*+, λ 4045 *Fe*, λ 4233 *Fe*+.

The symbols "pq" are used to indicate peculiarities of a character suggestive of the spectrum of Novae.

The exclamation symbol "!" may be used as a modifier to indicate very marked degree in a phenomenon. Thus "e !" means that the

emission lines are exceptionally strong; "p !" that the peculiarities are remarkable.

Examination of the notes to Miss Cannon's classification of spectra in *Harvard Annals*, **28**, **56**, and **93**, shows that the proposed notation will cover almost all the peculiarities which occur at all frequently, with certain exceptions. The most notable of these are spectra of Class A showing unusual strength of the silicon lines $\lambda\lambda$ 4128, 4131 (as in α Doradus), or of the strontium line λ 4077 (as in δ Normae). An examination of the proper motions indicates that stars showing these peculiarities are distinctly brighter than the average; but further study will be required before it can be determined with certainty whether these characteristics are associated with the "c" or "g" characters, or are independent of these, and to what degree they are connected with one another.

Pending such study, they may still be called A0p, A2p, etc., the question of a notation for their peculiarities being postponed.

Some of the more difficult objects, such as η Carinae and SS Cygni have been classified on a provisional basis to show the capabilities of the method.

VI. EXAMPLES OF THE PROPOSED NOTATION

c-Stars		*Giants*		*Dwarfs*	
ϵ Canis Majoris	cB1	γ Velorum	Oap	α Canis Minoris	dF5
β Orionis	cB8	ζ Puppis	Od	β Virginis	dF8
η Leonis	cA0	29 Can. Maj	Oe	The Sun	dG0
α Carinae	cF0	ι Orionis	Oe5	μ Herculis	dG5
α Persei	cF5	ϵ Orionis	B0	70 Ophiuchi Br.	dK0
α Ursae Minoris	cF8	γ Orionis	B2	70 Ophiuchi Ft.	dK4
ζ Geminorum	cG0	α Gruis	B5	61_1 Cygni	dK8
5 Lacertae (Boss 5804)	cK2	α Lyrae	A0	Lal. 21185	dM3
α Scorpii	cM0	β Leonis	A5	Barnard's Star	dM0
		θ Scorpii	gF0		
		ϵ Ceti	gF5		
		τ Persei	gG1		
		η Piscium	gG5		
		α Boötis	gK0		
		α Tauri	gK5		
		δ Virginis	gM0		
		β Pegasi	gM3		
		45 Arietis	gM8		
		B.D.+42°2811	R0		
		−3°1685	R5		
		19 Piscium	N0		
		+67°350	N2		
		VX Andromedae	Nc		

Nova Type

Qa	Nova Aquilae	1918 June 8–9
Qb	Nova Aquilae	June 10–13
Qc	Nova Aquilae	June 14–20
Qx	Nova Aquilae	June 21–July 1
Qy	Nova Aquilae	July 1, 1918–Oct., 1919
Qz	Nova Aquilae	1920–21
QzO	Nova Geminorum	February, 1914

Red Stars

π_1	Gruis	S
R	Cygni	Se
R	Geminorum	Se
R	Andromedae	Se

Wide and Double Lines

δ Orionis	Bonk	
α Eridani	B5n	
α Leonis	B8n	
α Aquilae	A5n	
δ Geminorum	A7n	
S Antliae	A6n A6n	or A6n+A6n
W Urs. Maj.	dF8n dF8n	or dF8n+dF8n
β Scorpii	B1k B1	or B1k+B1
μ Scorpii	B3 B3	or B3+B3
β Aurigae	A0 A0	or A0+A0
α Aurigae	gG0 F5	or gG0+F5
V Puppis	B1 B3	or B1+B3
o Leonis	cF5 A	or cF5+A
U Sagittae	B8 gG2	or B8+gG2

Bright Lines

γ	Cassiopeiae	Boe
η	Tauri	B5ea
β	Lyrae	cB8+B2nep
P	Cygni	B4eq
α	Cygni	cA2ea
RT	Serpentis	cF0e
RZ	Ophiuchi	cF8e
W	Virginis	cF7e
σ	Geminorum	gK1e
T	Tauri	gG5e
	Comp. α Gemin.	dM0+dM0e
T	Aquarii	M1e
o	Ceti (max.)	M6e
o	Ceti (min.)	Mvep !
R	Leonis	M8e
T	Coronae Bor.	M5epn
R	Aquarii	M6e+P
28	Tauri (Pleione)	B8ev
φ	Persei	Bpevr
	+11°4673	Beqpv
η	Carinae	Qp !
SS	Cygni maximum	B8n !q
SS	Cygni minimum	Opq
R	Cor. Bor.	cF5ep
H.D.	42474	gMoep !

DISTRIBUTION OF THE VELOCITIES OF STARS OF SPECTRAL TYPE A[1]

By GUSTAF STRÖMBERG

ABSTRACT

Velocity-distribution of A-type stars.—The three velocity-components for 332 stars of spectral types B7 to F2 have been computed from their proper motions, radial velocities, and spectroscopic parallaxes. The method used is that previously used for types F and M. The study of the distribution of the velocities reveals the existence of three well-defined groups, the *Central group*, the *Ursa Major group*, and the *Taurus group*, whose relative proportions among the stars studied are 69, 23, and 8 per cent. The Central group, which can be identified with the stream O of Halm and the antapex stream of Eddington, is shown to have an ellipsoidal distribution. Among the A stars, Kapteyn's First and Second streams can be identified with the Taurus and the Ursa Major groups, respectively. The elements of ellipsoidal distribution-functions for all three groups are given in Table III.

The Sun's velocity referred to the A stars is somewhat smaller than that found for other spectral types, on account of the presence of a large proportion of stars whose motion is nearly the same as that of the Ursa Major group.

A study of the velocities of stars of spectral types F to M was recently published in this journal.[2] A similar investigation of the stars of type A has been made possible by a recent application of the spectroscopic method by Adams and Joy[3] to the determination of the absolute magnitudes of stars of this type. In the latter paper the spectroscopic parallaxes of about 500 stars of spectral types B7 to F2 are given, all of known proper motion.[4] For 332 of these, radial velocities have been determined at the Lick, Mount Wilson, and the Dominion Astrophysical observatories, and hence it was possible to calculate the three velocity components.

These velocity components, relative to the sun and in the equatorial system of co-ordinates, were computed by the formulae:

$$\left.\begin{aligned}\xi &= V\cos\alpha\cos\delta - \frac{k}{\pi}(\mu_\alpha \sin\alpha\cos\delta + \mu_\delta\cos\alpha\sin\delta)\\ \eta &= V\sin\alpha\cos\delta + \frac{k}{\pi}(\mu_\alpha\cos\alpha\cos\delta - \mu_\delta\sin\alpha\sin\delta)\\ \delta &= V\sin\delta \qquad\quad + \frac{k}{\pi}\mu_\delta\cos\delta\end{aligned}\right\} \tag{1}$$

[1] *Contributions from the Mount Wilson Observatory*, No. 257.

[2] *Mt. Wilson Contr.*, No. 245; *Astrophysical Journal*, **56**, 265, 1922.

[3] *Mt. Wilson Contr.*, No. 244; *Astrophysical Journal*, **56**, 242, 1922.

[4] In the following the stars belonging to this range of spectral class are all called "A stars."

where V is the radial velocity relative to the sun, μ_α and μ_δ, the proper motions in right ascension and declination expressed in seconds of arc per year, π, the parallax, and where $k=4.737$ km/sec.

For the study of the distribution of the velocities, these components were referred to the galactic system of co-ordinates and to the origin used in the study of the velocity distribution for stars of later types. The reduction to this origin assumes a solar motion of 20 km toward the apex $A_0=270°$, $D_0=+30°$. The equations for finding the galactic co-ordinates, referred to the adopted origin, from the equatorial co-ordinates are:

$$\left.\begin{aligned} x&=+0.185\,\xi-0.983\,\eta+17.0 \\ y&=+0.449\,\xi+0.084\,\eta+\ 0.889\,\zeta+7.4 \\ z&=-0.874\,\xi-0.164\,\eta+\ 0.457\,\zeta+7.4 \end{aligned}\right\} \tag{2}$$

The stars were divided into two groups, according to their absolute magnitudes. Various data for these groups are given in Table I.

TABLE I

	Group I	Group II
Absolute Magnitude	≤ 1.1	≥ 1.2
Spectrum	B7 to A3	A1 to F2
c_1	40 km	40 km
c_2	30 km	30 km
c_3	30 km	30 km
Number of stars	159	173
Number within limits	152	167
Number of stars belonging to the Taurus group	0	17
Number of stars belonging to the Ursa Major group	10	7

The quantities c are the limits of x, y, and z, respectively, within which the distribution of the velocities has been represented by a three-dimensional cosine-series according to the method devised in *Contribution* No. 245.[1] The numbers of recognized members of the Taurus and the Ursa Major groups are given at the end of the table.

THE SOLAR MOTION

If we take the algebraic means of the equatorial velocity components, referred to the sun as origin, we obtain the velocity of the

[1] *Astrophysical Journal*, **56**, 265, 1922.

center of mass of the group studied relative to the sun. The opposite vector is the velocity of the sun relative to this "centroid." The velocity of the sun defined in this way is given in Table II for the two groups in question, both in equatorial and galactic coordinates.

TABLE II

Groups	Number	A_0	D_0	V_0	L_0	B_0
				km		
I........................	159	258°.4	+38°.0	12.0	29°.2	+33°.1
II........................	173	262.0	+19.2	14.0	9.7	+24.6
Omitting Taurus stars....	156	256.5	+29.4	11.5	18.8	+32.7
All........................	332	260.7	+27.4	12.8	17.9	+28.7
Omitting Taurus stars....	315	257.4	+33.8	11.7	24.1	+33.0

A remarkable fact is the small velocity obtained for the sun relative to these stars. As will be shown later, this is due to the circumstance that there exists a large number of stars whose motion is nearly the same as that of the Ursa Major group.

DISTRIBUTION OF VELOCITIES

An unbiased idea of the general character of the distribution of the velocities can be secured from a representation of the velocity-vectors with the aid of a trigonometric series in three dimensions. The formulae for this computation are all given in *Contribution* No. 245. No stars were omitted in this study except those outside the limits given in Table I. In figures 1 and 2 are shown the results of the synthesis of the trigonometric series in the form of closed curves. These are the intersections of the equi-frequential surfaces with the galactic plane. The numbers attached to the curves are the corresponding "densities," i.e., the number of velocity-vectors which terminate in a cube of unit size whose center is situated on the curve. These numbers are comparable with those given in the previous paper, and refer to a total of 1000 stars and a unit volume of 1000 cu. km. In order to emphasize that we are dealing with the frequency-function itself, and not with its integrated values, we might rather say that the density numbers are reduced to a total of 1,000,000 stars and a unit volume of 1 cu. km. The dots in the

diagrams represent velocities of individual stars, so that the vector from the origin to a dot is the projection on the xy- or the xz-plane of the velocity-vector referred to the same origin. In the xy-plane only those velocities are indicated whose z-components are numerically smaller than 10 km, and similarly for the xz-plane. The recognized members of the Taurus group are indicated by crosses,

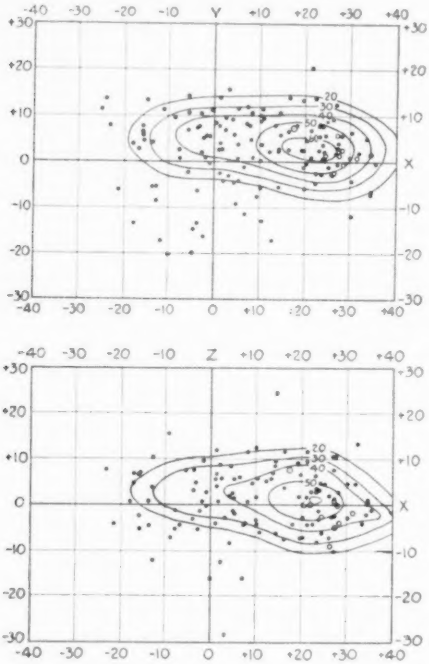


FIG. 1. $M \leq 1.1$

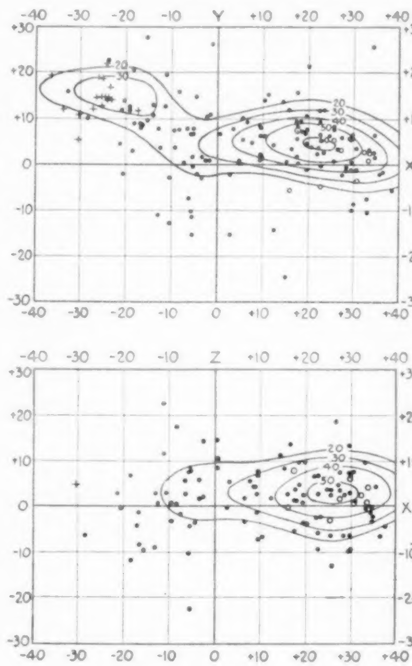


FIG. 2. $M \geq 1.2$

those of the Ursa Major group by open circles. The velocity of the sun is indicated by the symbol ⊙.

An inspection of these diagrams gives us immediately some valuable information. In the case of the brighter A stars (Fig. 1), the point of highest density, the condensation point, does not fall at the origin, and not even near the center of the outer equi-density curves, but at a point which corresponds nearly with the group-motion of the Ursa Major stream. The most frequent velocity among these A stars is thus nearly the same as that of the Ursa Major group. The same holds for the group of fainter A stars

(Fig. 2); but in addition we have a group of stars forming a second condensation point in the second quadrant of the xy-plane. Most of the stars belonging to this last group are recognized members of the Taurus group. Actually we can distinguish three groups of stars, the Central, which is the most numerous, the Ursa Major group, and the Taurus group. As is well known, there are other moving groups, but their members are few in number, and the real existence of the groups can be proved only by some distinguishing characteristic other than apparent parallelism of motion, as, for instance, an actual grouping of the stars in the sky.

Having found these qualitative data, an attempt was made to determine the three frequency-functions the sum of which constitutes the actual distribution function. All the A stars except those belonging to the Taurus group were studied together. It was thus sufficient to determine the constants of two frequency-functions, corresponding to the Central group and to the Ursa Major group. Both of these frequency-functions were supposed to be ellipsoidal and the method used in *Contribution* No. 245 could accordingly be applied. The equations of condition thus take the form:

$$\left.\begin{aligned} dn=\mu dN_1+(1-\mu)dN_2+(N_1-N_2)d\mu+n_c\kappa=n_0-n_c \\ dN_1=\frac{dN_1}{dh_1}\Delta h_1+\frac{dN_1}{dh_2}\Delta h_2+\frac{dN_1}{dh_3}\Delta h_3 \\ +\frac{dN_1}{dx_0}\Delta x_0+\frac{dN_1}{dy_0}\Delta y_0+\frac{dN_1}{dz_0}\Delta z_0 \\ +\frac{dN_1}{dL_1}L_1+\frac{dN_1}{dB_1}B_1+\frac{dN_1}{dB_2}B_2 \end{aligned}\right\} \qquad (3)$$

with a similar expression for dN_2. The expressions for

$$N_1, \quad \frac{dN_1}{dh_1}, \quad \frac{dN_1}{dh_2}, \quad \text{etc.,}$$

are given in the paper cited. Further,

$$n_c=\mu N_1+(1-\mu)N_2$$

where $\mu/(1-\mu)$ is the proportion of stars belonging to the Central group relative to that of the Ursa Major group. There are in all

twenty unknowns, but by choosing the volumes in which the number of velocity points are counted in such a way that they are symmetrically placed relatively to the assumed center of one of the groups, we can make several of the product-sums equal to zero, which facilitates the solution considerably. The results of this computation are given in Table III, in galactic co-ordinates relative to the adopted origin, and in equatorial co-ordinates relative to the sun.

The position of the center of the Central group agrees well with that found for the center of the velocity-ellipsoids for later-type stars in the study of those objects. The large uncertainty found for the major axis of the ellipsoid belonging to this group, and for the number μ which determines the relative proportion of stars belonging to the Central and to the Ursa Major groups, is due to the fact that it is possible to represent the distribution (excluding the stars belonging to the Taurus group) by a single frequency-function of the ellipsoidal type. In this case we have $\mu=1$. But there is no doubt that a much better representation could be secured by using the sum of two frequency-functions, one representing the distribution in the Central group, the other that of the Ursa Major group.

The position of the center of the Ursa Major group as given in Table III does not agree exactly with the values ordinarily given for the convergence-point and for the velocity of this group. The values recently published by Rasmuson[1] are:

$$\alpha=307\overset{\circ}{.}6\,, \qquad \delta=-39\overset{\circ}{.}9\,, \qquad v=18.6 \text{ km}$$

while our values are

$$\alpha=306\overset{\circ}{.}5\,, \qquad \delta=-25\overset{\circ}{.}9\,, \qquad v=13.0 \text{ km}$$

As can be seen from the diagrams, the recognized members of the Ursa Major group, which are marked by open circles, lie somewhat to the right of the point of highest condensation. We cannot distinguish the Ursa Major group, as defined by its recognized members, from that revealed by the general excess of stars moving in this direction, and we are thus justified in using the name of the Ursa Major group to designate this whole group of stars.

[1] *Meddelanden från Lunds Observatorium*, Serie II, No. 26.

The orientation of the velocity-ellipsoid for the Central group agrees well with that for the giant stars of later types, and the dispersion along the axis is similar to that for the F stars of high luminosity. The velocity-ellipsoid of the Ursa Major group presents the remarkable feature of a prolate ellipsoid with the longest axis pointing toward the pole of the galaxy. The spread, both for the Central group and for the Ursa Major group, is to some extent increased by the effect of errors in the proper motions, radial velocities, and distances; but the general features of the frequency-functions cannot be affected much by this circumstance.

The algebraic means of the velocity components of twelve recognized members of the Taurus group are given in the fourth column of Table III, together with the equatorial co-ordinates relative to the sun of the velocity-vector of the group. These may be compared with Rasmuson's elements,[1] which are nearly identical with Boss's original values, viz.,

$$\alpha=93^\circ.2\,, \qquad \delta=+7^\circ.0\,, \qquad v=40.5 \text{ km}$$

In the last column are given the elements for the Taurus group, including eight additional stars, which, as judged from their motions, are members of the group, although their position in the sky differs from that of the recognized members.

The constants of the ellipsoidal distribution of the Taurus group are given in the last column of Table III and are computed directly from the moments. The spread is small and can well be accounted for by accidental errors in the quantities involved. It is significant, however, that the Taurus group among the A stars has a small spread and is at the same time largely limited to the constellation of Taurus, whereas the Taurus group as defined by the F stars has a larger spread and its members are scattered all over the sky. (See remark on the Taurus group in *Contribution* No. 245.) This indicates that the central part of the Taurus group is actually situated in the constellation of Taurus, but there are members, presumably of smaller mass, which, on account of larger "peculiar" motions, have been scattered over a larger space.

[1] *Loc. cit.*

The Central group found among the A stars can be identified with the antapex-stream of Eddington[1] and with the O stream of Halm.[2] As mentioned before, it can also be identified with the ellipsoidal group to which all giant stars of later types belong,

TABLE III

CONSTANTS OF THE DISTRIBUTION-FUNCTIONS

		Central Group	Ursa Major Group	Taurus Group	
		km/sec	km/sec	km/sec	km/sec
Position of center	X_0 . . .	+5.0±6.1	+27.5± 1.3	− 26.4	− 25.1
	Y_0 . . .	+1.8±0.8	+ 4.7± 0.9	+ 14.3	+ 13.5
	Z_0 . . .	+2.4±0.5	+ 0.3± 1.3	+ 5.4	+ 5.6
	α_0 . . .	91°.7± 6°.0	306°.5± 6°.1	105°.1	114°.9
	δ_0 . . .	−31°.0±13°.1	− 25°.9± 5°.6	+ 6.8	+ 6.1
	V . . .	14.2± 5.2 km	13.0± 1.3 km	44.0km	42.6km
Orientation of ellipsoids and dispersion along principal axis	a	$21.4\begin{cases}+36.1\\-8.2\end{cases}$ km	$9.69\begin{cases}+3.91\\-2.17\end{cases}$ km		5.2km
	L_1 . . .	158° ±22°	146°.0		324°
	B_1 . . .	− 6.8± 4.2	+ 83.2±16.8		+ 21
	α_1 . . .	84.0	184.1		244
	δ_1 . . .	+ 16.1	+ 30.8		− 18
	b	8.54± 0.66km	5.52±0.34km		4.3km
	L_2 . . .	65° ±20°			48°
	B_2 . . .	− 22 ± 9			− 16
	α_2 . . .	342			323
	δ_2 . . .	+ 34.9			+ 31
	c	6.73± 0.59km	5.48±0.94 km		2.1km
	L_3 . . .	84° ±12°			104°
	B_3 . . .	+67 ± 8			+ 63
	α_3 . . .	194			180
	δ_3 . . .	+50			+ 53
Relative proportion. .		75.0±23.4 per cent	25.0±23.4 per cent		
Number of stars used in determining constants.		307		17	25

except 20 per cent of the fainter F stars, which belong to the Taurus group. This Central group, to which the vast majority of the apparently bright stars seem to belong, has a fixed group-motion and orientation of the axis of its velocity-ellipsoid, but the dispersion increases regularly from the A stars to the M stars, while the prolateness of the velocity-ellipsoid decreases.

[1] *Monthly Notices*, **71**, 40, 1910. [2] *Ibid.*, p. 610, 1911.

So far as the A stars are concerned, the Taurus and Ursa Major groups can also be identified with Kapteyn's First and Second streams. Since this class of stars is very numerous, the division into two streams is very marked among the stars in general. The ellipsoidal nature of the frequency-distribution for the Central group of types A to G, when studied from the standpoint of proper motion or radial velocity, could not be distinguished from two separate streams. When Kapteyn made his original discovery and determination of stream-motion, the frequency-distribution of proper motions for different regions in a zone at the same angular distance from the sun's apex was determined. The mean of these distributions was formed and the deviations from this mean distribution were determined for each region of the zone. Since the mean distribution corresponds closely with that of the Central group, this group, as has been pointed out to the author by Mr. Seares, was almost entirely eliminated from Kapteyn's discussion when the differences were studied. The distribution described by Kapteyn was that remaining after a central, random (spherical) distribution had been subtracted. This Central group of stars, appearing later in the investigations of Halm and Eddington, is now found to be the most numerous and to have an ellipsoidal distribution in agreement with the theory of Schwarzschild and Charlier.

MOUNT WILSON OBSERVATORY
October 1922

VACUUM ARC FOR OBTAINING SPECTRA EXTENDING FROM VISIBLE LIGHT TO SOFT X-RAYS

By H. Nagaoka and Y. Sugiura

ABSTRACT

New vacuum arc with salted carbon cathode.—A simple type of arc is described which, with 2–5.5 amperes at from 80–150 volts, is an intense source of very sharp lines. The cathode is a carbon rod covered with a layer of the oxides of Ba and Sr and sheathed up to the end in a fused silica tube. The anode consists of the metal or salt to be tested placed in another silica tube. These tubes are fastened in necks of the vacuum flask by means of rubber stoppers made tight with Khotinsky cement and water-cooled. Light passes to the spectrograph through a quartz window or right-angled prism. After exhausting the flask to a low pressure, a glow discharge is started by means of an induction coil and then the electrodes are rapidly switched to the poles of the 500 volt D.C. generator. Low melting-point metals tend to deposit on the window, but spectra of all metals including tungsten may be obtained. The oxide layer on the cathode must be renewed occasionally. The cyanogen bands appear with a weak current, but vanish with a strong current. The *sharpness of the lines* was tested with a Fabry-Perot etalon interferometer and more distinct interference fringes were obtained than in the case of lines from a Pfund arc (Plates III*a* and III*b*). As a *standard source* the vacuum arc has other obvious advantages, since it eliminates various uncertain effects of pressure and electric field.

Vacuum arc as source of soft X-rays.—When the potential was raised to 1500 volts, using the rectified current from a transformer, rays were emitted which affected a photographic plate covered with one to three aluminum foils, placed within the flask. The minimum wave-length is computed, from the quantum relation, to be 10 A. No effect was obtained at 80 volts.

For purposes of spectroscopy, it is always desirable to obtain a light-source of sufficient purity and intensity, so that the lines can be examined by means of interferometers. Sparks and arcs in air are unfit for the purpose; the light excited by cathode bombardment fulfils this condition, but the arrangement is generally complex, and the duration of light-emission not long enough to obtain a good impression on a photographic plate. To overcome some of the inconveniences attending the handling of a limed cathode and to increase the effective duration of light, the lamp here to be described was designed.

One[1] of us has already solved a portion of the problem by replacing an oxide-covered platinum strip in the Wehnelt cathode by a thin carbon plate. With this change, the Wehnelt cathode was

[1] *Astrophysical Journal*, **53**, 323, 1921.

somewhat simplified, but the tedious process of excitation remained unimproved. In the present form the same idea was followed, but great simplification in removing the material and in making the oxide-covered cathode is introduced.

The essential part of the apparatus consists of a three-necked flask of about a liter capacity, as shown in the figure. An India-rubber stopper *a* has a carbon rod *c* inserted into it, and the rod is sheathed in a closely fitting silica glass tube: the end of the rod is first dipped in a solution of barium and strontium nitrate, and heated in a Bunsen burner, so that the surface of the carbon appears white, being covered with the oxides of barium and strontium. A thick copper wire *b* is screwed into the rod to have good contact, and passes through an India-rubber stopper which is covered with Khotinsky cement to make it air-tight. The substance to be tested is put into another fused silica tube *d*, which fits into an India-rubber stopper *e*, the substance and the electrode being electrically connected within the tube by means of a carbon rod. On inserting the stopper, the neck is sealed by Khotinsky cement. The end of the neck *f* is ground plane, and a right-angled prism *p* of quartz cemented on it. The air within the flask is evacuated by means of a Gaede mercury pump, having a condensation pump in series to obtain a good vacuum. On running the pumps for a few minutes, the manometer indicates that the flask is pretty well exhausted; the carbon rod is then connected to the cathode and the substance to be tested to the anode of a small induction coil, by which the carbon pole is covered with "Glimmlicht." The electrodes are then rapidly switched to the poles of a 500-volt D.C. generator, and the current kept at proper strength, which

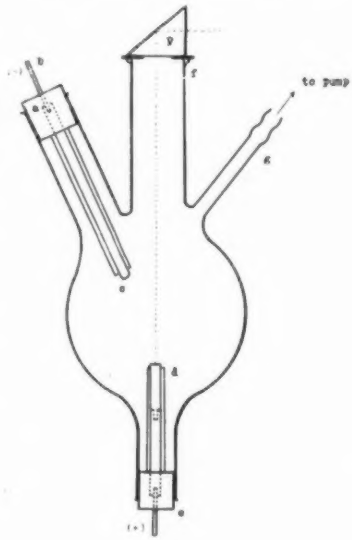


FIG. 1

varies with the nature of the substance to be tested. With most metals, 2 or 3 amperes with terminal voltage of 80 to 90 volts are sufficient to give intense light, the fluctuation of the current being scarcely noticeable. With the spectrograph, described below, a few seconds suffice to obtain spectrograms of the violet region. To obtain a very intense source of light, the current is pushed to 5.5 amperes; the evaporation of the anode material is very rapid, the terminal voltage being kept at 150 volts. Care is taken not to make the tip of the carbon interfere with the passage of light into the total reflecting prism p. The cathode carbon is heated red hot, but its light is faint compared with that from the anode, and does not mix in the spectrum to be examined. With mercury, the stopper is dispensed with; the neck is made smaller, and mercury poured into it, the electrode of iron wire being cemented at the end of the neck. It was at first thought that the light would play round the surface of the mercury; this takes place only when the current is strong, otherwise a steady bright bundle of light, resembling a tuft, is seen protruding from the surface. To prevent heating and the softening of the cement, two-thirds of the flask is immersed in a trough of running water. Salts may also be introduced into the silica tube d and their spectra investigated. So long as the current is not broken, the light continues to be emitted till the greater part of the anode material is evaporated by the bombardment. When the oxide is evaporated, it is difficult to relight the lamp. With certain substances as zinc, the wall is covered with fine particles of evaporated material, and the fogging is so great that a bright source of light is hardly visible through the wall. There is, however, no difficulty in obtaining spectra of highly refractory metals, such as tungsten. With easily evaporating substances as mercury, the face of the prism is slightly dimmed by the vapor rising from the anode; to prevent this it is advisable to introduce diaphragms in the neck below the prism.

By making the capacity of the flask bigger, we may perhaps dispense with the water-cooling. The necks a and e may be made somewhat conical and ground so as to fit tightly into glass stoppers, which have the electrodes fused into them. A wire of platinum

substitute, used in electric lamps, will form suitable external electrodes: they will secure good contact with glass, as the thermal expansion of both substances may be made equal.

As will be easily seen from the construction of the flask exciting the light, the arrangement of the anode and cathode is exactly analogous to a Coolidge X-ray tube; if the difference of potential between the electrodes be made sufficiently high, X-rays must be emitted. The current of a small step-up transformer was rectified by means of a kenotron and passed into the flask, the potential difference between the electrodes being about 1500 volts. Three strips of thin aluminium foil were placed one over the other, so that they formed layers of three different thicknesses, and laid on a photographic plate. It was wrapped with black paper and placed in the neck of the flask under p, and exposed to the action of rays for 15 minutes. Zinc, silver, and mercury were used as anodes; on developing, the plate was blackened each time, showing the gradations according to the thickness of the aluminium foil. By placing a wing of a butterfly on the plate, and photographing in the same manner, the veins distinctly screened the photographic action. Calculated from quantum relation, the wave-length in these experiments is a little shorter than 10 A. The same experiment was repeated with a terminal voltage of 80 volts, but the plate showed no sign of blackening, although intense visible light was excited under it. By applying sufficiently high voltage, it would be possible to obtain hard X-rays, if good vacuum be maintained.

Since there was no vacuum spectrograph at hand, the Schumann region was not examined, but the emission of soft X-rays sufficiently proves that the emitted light extends to the extreme ultra-violet. In the present apparatus, it is evident that by applying proper terminal voltage, we can excite light waves ranging from the visible to the ultra-violet, and extending even to soft X-rays.

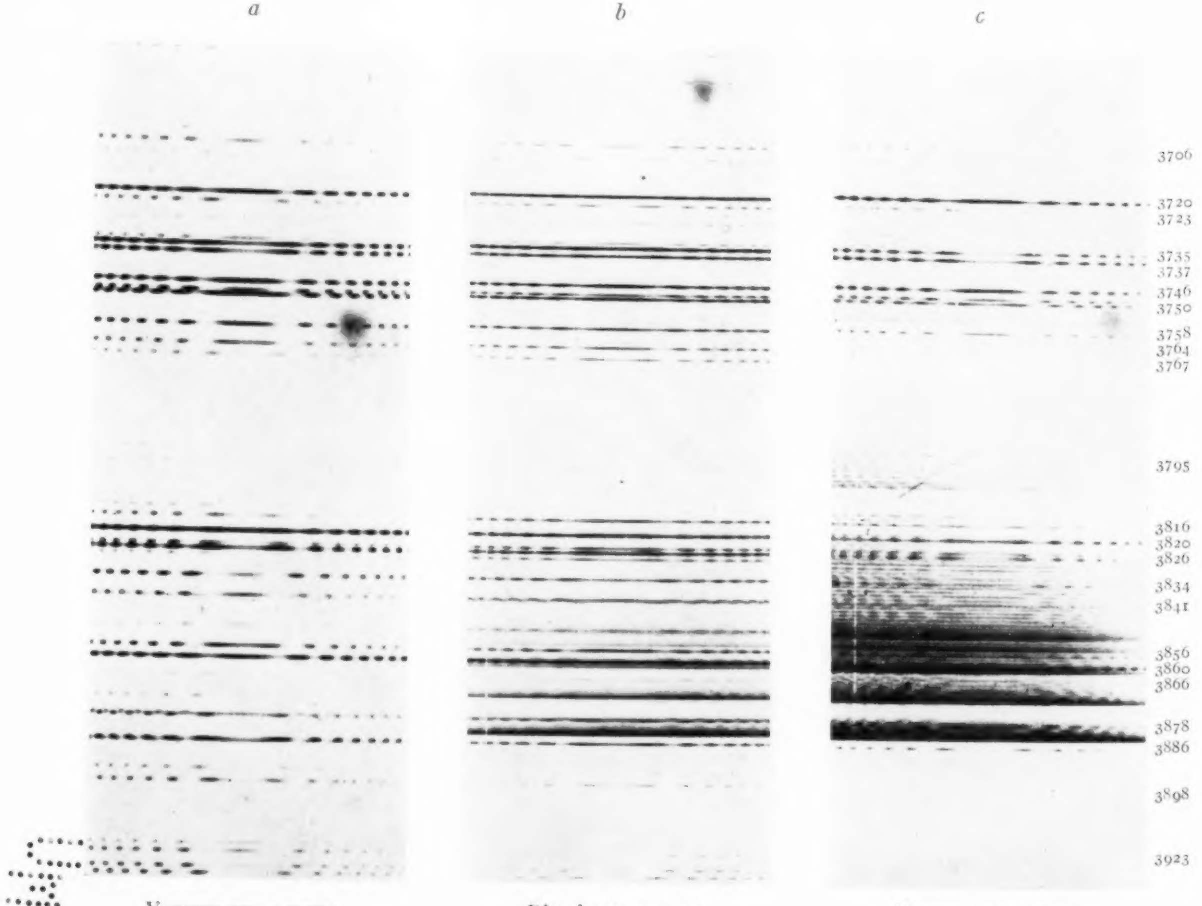
The purity of the spectrum was tested in the following manner. An arc of electrolytic pure iron was excited and compared with the Pfund arc of ordinary iron, by passing the light through a Fabry-Perot interferometer of etalon type, the silvered plates being separated by a fused silica cylinder 1.01625 cm long. The interference

rings were projected on the slit of a Hilger quartz spectrograph on a Littrow mounting; it was provided with a quartz lens (aperture 7 cm, focal length 170 cm) and a quartz prism (refracting angle 30°, 9.8×5.7 cm face) silvered on the back, and so arranged that the spectrum could be photographed nearly at minimum deviation. The Pfund arc was 6 cm long at 500 volts. The middle portion of the arc was used. The fringes from the vacuum arc were sharply defined as shown in Plate III*a*, which represents a small portion of the violet region. With the Pfund arc the fringes are not sharp (Plate III*b*); they are bridged and the mean points difficult to measure. Usually the length of the Pfund arc is 6 mm or so at 200 volts, but the length of the arc can be extended to 6 cm working at 500 volts, making the fringes more distinct, although they are lacking in definition compared with those of the vacuum arc, as the inspection of the figures will show. By increasing the thickness of the air plate in the Fabry-Perot interferometer, they can be made more distinct apparently, but the same relative difference in fringes of these two sources of light will persist.

For accurate comparison of wave-lengths, the interference method is generally applied; for this purpose it is necessary to obtain sharp fringes, whose position can be measured with great accuracy. The preference for the vacuum arc instead of that in air requires no further comment.

The curious characteristic of the vacuum arc here described is the appearance of cyanogen bands for weak electronic current. With iron as the anode, most of the iron lines appear, but those lying in the region of the cyanogen bands are mostly obliterated so that it is difficult to trace their faint presence. The bands are, however, very strong and show their characteristics to a high degree. They gradually disappear as the current is increased; when a certain strength is exceeded, they vanish and only the iron lines remain. Plate III*c* shows the latter stage. The bands are all capable of high interference, and can be examined by a Fabry-Perot interferometer or a Lummer-Gehrcke plate. The Pfund arc shows the same phenomenon, especially at high voltage. In the vacuum arc, the bands are probably excited by electronic bombardment of nitrogen, to

PLATE III



Vacuum arc, 5 amps. Pfund arc, 3 amps. Vacuum arc, 3 amps.

which they are due, the presence of cyanogen not being necessary according to Runge. Owing to dissemination of carbon particles within the flask, there is, however, great chance for the production of cyanogen within the apparatus.

The study of the structure of the iron lines and of the cyanogen bands obtained by the present method will be reserved for a future communication.

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August 2, 1922

A COMBINATION OF A CONCAVE GRATING WITH A LUMMER-GEHRCKE PLATE OR AN ECHELON GRATING FOR EXAMINING FINE STRUCTURE OF SPECTRAL LINES

By H. NAGAOKA AND T. MISHIMA

ABSTRACT

New method of studying the fine structure of spectrum lines; concave grating in series with a Lummer-Gehrcke plate or an echelon grating.—Because of the astigmatic property of the concave grating, fringes projected on to the slit parallel to the rulings are drawn out, and the components, if not too faint or too close together, are made more distinct. The slit should be wide enough to include two or three orders. In the case of the L.G. plate, photographs with two plates of different thickness will give the order numbers. This method should be useful in the study of the Stark and Zeeman effects and for the rough analysis of diffuse lines such as those from arcs and sparks in air. For a minute study of the structure, the method of crossed spectra is superior though the loss of intensity is considerable. Results obtained are illustrated by four spectrograms showing: Hg, λ 2536; the Hg triple, $\lambda\lambda$ 3663, 3655, 3650; Hg, λ 5461; and some iron lines from a Pfund arc.

Of the various methods of examining the structure of spectral lines, most accurate results are obtained by forming crossed spectra of lines with interferometers. The lines are, however, generally diffuse, and not sharp enough to apply the method, when the arc or spark is excited in air. Only by using vacuum arcs can we effectively examine the fine structure of spectral lines. Some means of overcoming this difficulty and of making the study of the structure easier is necessary, in order that we may be able to get some insight into the perturbations of electronic movement in atoms. The method which we shall now develop will be of some significance in investigations of similar nature, such as the study of the Zeeman or Stark effect.

Of the different interferometers which are used for examining the structure of lines, we may mention Michelson's echelon grating, the Lummer-Gehrcke plate, and the Fabry-Perot interferometer. All these instruments have the common defect that for using them the source of light must be pure; diffuse lines, although some difference in intensity may exist among the components, cannot be analyzed by such means. The fringes of interference are merely blurred images of lines without definite boundary. Such, for

example, is the case with the sodium lines from a Bunsen flame, or the cadmium lines excited by an electric spark in air. It is, however, well known that the concave grating, by virtue of its astigmatic property, can effectually analyze most of the lines, which are not resolvable by the interferometers above mentioned; this is especially the case in the study of the Zeeman effect of most of the light metals. This important characteristic can be taken advantage of in the investigation of the fine structure of lines, but owing to the low resolving power of most of the gratings, there is still some advantage in using the interferometers. The method which we shall describe consists in the combination of these two instruments, so that we may be able to utilize, on the one hand, the high resolving power of the interferometers, and on the other, the astigmatism of the concave grating.

The usual practice is to analyze the light roughly into its spectrum and examine one of its lines by means of an interferometer. In the present method the order is inverted. The light from a source is directly received on the slit of an interferometer, and the interference spectra thus obtained are projected on the slit of a concave grating. The slit is kept tolerably wide, so that two or three successive orders of interference spectra can be received on it. Great care is needed to bring the projected lines parallel to the rulings of the grating. The parallelism can be easily obtained by a direct observation on the visible part of the spectrum, for the lines appear very distinct when this condition is fulfilled.

The absence of the dust lines of the slit used in observations with the concave grating is a point which we can properly turn into an important application to the problem at hand. Owing to the astigmatic property of the spherical surface, a point is drawn out into a line, whose length is approximately given by $l \sin \theta \cos \theta$, where l is the length of the rulings, θ the angle of diffraction in the case of Rowland mounting. Thus the length of the slit is very much elongated from its natural length; consequently the distribution of complex lines projected on the slit is more distinct, and gives better definition to the appearance of the lines than when observed with interferometers only. The spectrum as given by a Lummer-Gehrcke plate consists of a number of straight lines; if we project

these lines on to the slit of a concave grating, they will, after diffraction, appear as distinct lines, the blurred edge of the component lines being wiped away just as the dust lines of the slit are eliminated. The complex lines, as observed in this manner, are not exactly similar to lines analyzed by the plate. Owing to the slight difference of wave-lengths among the components, the mutual position will be affected to a small extent by diffraction, and thus indicate minute differences in the interval between them. The appearance of the lines is made very distinct by this method of observation, so that we have no difficulty in delineating the separate components, which otherwise would have presented a diffuse appearance, especially when we use an arc at ordinary atmospheric pressure. Even with a vacuum arc, we may sometimes find, by the usual method of observation, no great difference from the condition in air, especially with light metals and metalloids.

Denote the angle between the line joining the slit with the center of the grating and the line passing through the center of the sphere by θ, and the angle of diffraction by θ', then we have the approximate relation

$$\epsilon(\sin\theta+\sin\theta')=\pm h\lambda$$

where ϵ is the interval between successive rulings, and h the order of the spectrum. In the present method, we have to use a tolerably large slit, in order that more than one of the spectra from the plate may appear projected on the slit. Denoting the small change of angle by $d\theta$ and $d\theta'$, we have the relation

$$\epsilon(\cos\theta d\theta+\cos\theta' d\theta')=\pm h d\lambda.$$

For constant wave-length $d\lambda=0$, and

$$\cos\theta d\theta=-\cos\theta' d\theta',$$

giving the relation between the consecutive spectra. For Rowland mounting

$$d\theta'=-\cos\theta d\theta,$$

and for Littrow mounting

$$d\theta'=-d\theta.$$

Since λ is nearly constant, we have the images of the components of luminous lines in inverse order at the point of observation from

those projected on the slit. From the constant of the grating, we can easily calculate the displacement of the line due to the small difference in the wave-lengths of the satellites from the principal; it is necessary to introduce this correction in exact measurements of the satellites. Another way is to take two photographs, such that the wave-length in one increases in the opposite direction from that on the other. The mean of these two readings will give the true value. This process can be easily effected by deflecting the plate in opposite directions and adjusting the interval so that it is the same in both cases between successive spectra. The correction due to this cause is generally small. Further, we notice the advantage of the Littrow mounting over that of Rowland, as is evident from the formula.

The great disadvantage of using the Lummer-Gehrcke plate lies in the difficulty of discriminating the order of the spectra to which the component belongs. There is no easy means of finding out the proper order except by crossing the spectra at right angles to each other; this entails a great deal of labor on the part of the experimenter, and what is worse there is great loss of intensity by this process. The method here given has some advantage over that of crossed spectra, as the question of the order of the spectra can be easily settled if we have two plates of different thickness. The advantage thus gained by the combination of the grating with the interferometers is not easy to estimate, since the study of some faint components is made possible by this means, and the discrimination as to the doubtful position of many lines with respect to the principal rendered possible without crossing. When there are faint components grouped together, the present method is still inferior to that of crossing, as will be shown farther on.

A quartz plate of thickness 4.529 mm made by Hilger was mounted vertically on a stand, and light of a mercury vacuum arc was made to fall on the plate after passing through a quartz lens and a Wollaston prism, so as to receive only the ordinary or extraordinary ray in the plate. The light which passed through the plate was projected on the slit of the grating by a quartz-fluorite lens; the slit was 2 to 3 mm wide; this was necessary as the spectra to be projected on the slit must be at least two or three in number, in order that the evaluation of the position of the satellites may

attain sufficient accuracy. Plate IV*a* shows the doublet structure of the mercury line 2536. The interval between successive spectra amounts to 0.0474 A, and that between the doublets is 0.0142 A, which coincides with the measurement of Miss L. Wilson[1] by a different process.

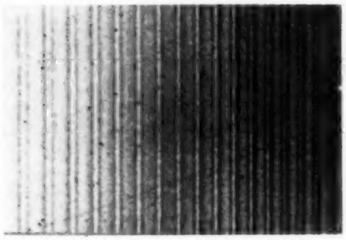
Experiments with an echelon spectroscope taught us that the structure of iron lines cannot be easily examined, and our knowledge of the fine structure of the numerous lines of that element is still vague. Recently we have found out that iron lines are resolvable by the L.G. plate, when analyzed by combining it with a concave grating. With the plate alone, the lines appear as strips with no definite boundary, but examined by interposing a concave grating, the lines become distinct; the slight blurring of the lines is probably due to the pole effect, as the focusing lens generally projects all parts of the arc on the plate. By taking the precaution to make only the central portion of the Pfund arc enter the plate, the lines become tolerably fine, so that, with a grating of 1.85-meters radius and 4-cm ruled spacing, and in the second-order spectrum of a Littrow mounting, the interval between the interference fringes belonging to the same line may be made as wide as 1 mm, and the interval can be measured with great accuracy. For $\lambda = 0.44\ \mu$, the difference of wave-length between successive spectra amounts to 0.17 A, equivalent to 1 mm on the photograph, and thus the measurement can be easily pushed to milliangstroms without incurring much error in the last figure. This point is of importance in the measurement of changes of wave-length of different elements in electric and magnetic fields.

Plate IV*b* shows three orders of interference spectra of iron lines. They are all simple. Of course different exposures are necessary for weak and strong lines; in the figure, strong lines are obliterated, but they come out distinctly by shortening the exposure.

With the echelon grating, the observation is made in the same manner as with the L.G. plate. On account of the use of glass plates in the construction of the grating, it is difficult to extend the investigation into the ultra-violet, but we were fortunate to photograph the triplet lines 3663, 3655, 3650, in the third-order spectrum, revealing the complex structure as shown in Plate IV*c*. The echelon

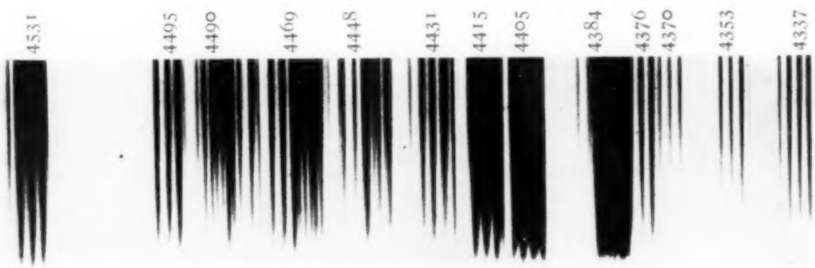
[1] *Astrophysical Journal*, **46**, 340, 1917.

PLATE IV



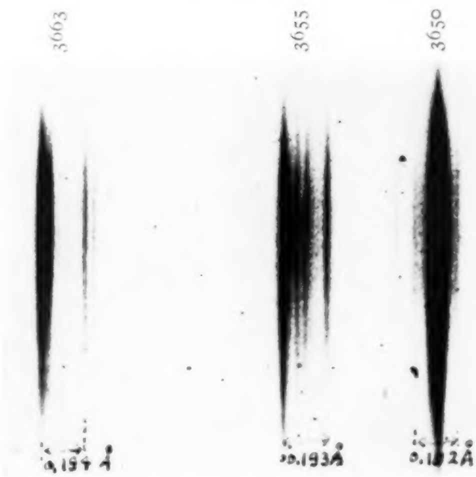
a

Hg 2536. L.-G. plate and concave grating.



b

Fe lines. L.-G. plate and concave grating



c

Hg lines. Echelon and concave grating

d

a: +0.083A
b: +0.128A
c: −0.237A
d: −0.103A
e: −0.069A

Hg. 5461
Echelon and concave grating

grating had thirty-five plates, of 9.36 mm thickness, with steps of 1 mm; the concave grating was the one already cited. Dr. T. Takamine has already photographed these lines with the echelon grating, by interposing a constant deviation prism; on account of the small dispersion of the prism the lines are closely packed, but with the concave grating they are well separated and the components decidedly better defined. The approximate position of the components is given in the diagram; the exact position obtained from crossed spectra of two quartz plates will be given in a future paper, which is now in course of preparation. Plate IV*d* shows the well-known green line of mercury obtained in the same manner; only five out of twelve satellites are found, the rest lying mostly in the neighborhood of the principal.

On examining the spectra thus obtained with concave grating combined with interferometers, we notice the advantage of the method when the component lines are not very near the principal. For obtaining exact position, the crossed spectra of two interferometers are still preferable. This is well exemplified in the mercury line 2536; Plate IV*a* shows that the principal components are a doublet, but there are vague traces of faint components whose position is difficult to make out. We lately found that there are, besides the doublet, at least four minor components, whose position can be exactly located by crossing two quartz plates. It is mostly in work on Zeeman and Stark effects that the present method of observation can be effectively used, provided the intensity of the components does not fall off or when they do not lie closely together. When the lines are diffuse, and have apparently no definite boundary, the combination here described will give better definition and facilitate the location of the mean position of the lines for measurements. Thus the advantage of using the present method will mostly lie in dealing with the arcs or sparks in air, while the crossed spectra can be used in accurate measurements with the light from vacuum arcs.

Finally, it may be pointed out that the combination of Fabry-Perot interferometer with a concave grating is impossible, as the fringes come out in circles instead of in straight lines.

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THE EXPLOSION SPECTRA OF THE ALKALINE EARTH METALS

By R. A. SAWYER and A. L. BECKER

ABSTRACT

Modification of Anderson's exploded wire source of light.—In 1920 Anderson obtained extremely high temperature spectra of certain metals by discharging a large condenser through fine metal wires. The authors have found that the metal wire may be replaced by an *asbestos fiber saturated with an aqueous solution of a salt* of the chosen metal. Thus the explosion spectrum of any soluble salt may be obtained. The fiber is uninjured by the explosion and may be used repeatedly. With a 6-foot grating, from six to twenty explosions are necessary for a first-order spectrogram. The condensers (0.3 M.F.) were charged to 40,000 volts through a high resistance with the rectified current from a 1-kilowatt transformer, and were discharged by means of a special switch. The apparatus and connections are described. The temperature of the explosion is probably about 15,000° C. and the pressure 10 to 20 atmospheres.

Explosion spectra of chlorides of Ba, Ca, Mg, and Sr, λ 2280–λ 4550.—When lines due to impurities, Cu, Zn, Al, Pb, C, and N, are eliminated, the spectra are found to be almost pure spark spectra, consisting chiefly of the doublets of the first and second subordinate series, $2p-md$ and $2p-ms$. Of the arc lines, only the fundamental singlet line, $1S-2P$, appears and its intensity with reference to the spark lines is only one-tenth as much as in the vacuum arc and about the same as in the spectra of the solar chromosphere and of class B stars. The first member of the Bergman doublet series of Mg, $3d-4f$, λ 4481, appears and also a line of Ba, λ 4350, whose series relation is unknown. No lines of Cl, H, or O were detected. The prominence of impurity lines shows how small an amount of material is needed to give explosion spectra.

Relation of explosion spectra to the theory of spectra.—According to Saha's theory, the metals used would be ionized at the expense of the less readily ionized Cl, H, and O; in fact at 15,000° C. the alkali earths should be almost completely ionized. Hence, according to Sommerfeld, the explosion spectra should be almost pure spark spectra. These conclusions agree with the facts. The faint arc lines may be emitted during the initial and final stages of the explosion. The Bergman line indicates an approach toward double ionization.

I. INTRODUCTION

In 1920 Dr. J. A. Anderson[1] announced a new method of producing spectra. This method consists of exploding a short fine wire of the metal chosen by discharging through the wire a large condenser charged to several thousand volts. If the explosion takes place in a confined space an absorption spectrum is produced; while if the explosion occurs in the open air or in a partial vacuum the spectrum partakes more of the nature of an emission spectrum. The exact type of spectrum produced depends, however, upon other factors besides the pressure.

[1] *Astrophysical Journal*, 51, 37, 1920.

One of the interesting features of this source of light is that it enables a very powerful stimulus to be applied very abruptly to the molecules of an element. It is thus possible to study spectra under conditions widely different from those obtaining in most laboratory sources.

In the course of some investigations with these explosions, which have been briefly reported elsewhere,[1] a modification of Anderson's source was announced. The fine wire used by Anderson is replaced by a fine asbestos fiber which is saturated with a solution of some salt of the desired metal. When the high tension condensers are discharged through this saturated fiber, with the fiber in the open air, an emission spectrum is obtained characteristic of the metallic ions in the solution.

It is the purpose of this paper to discuss the spectra produced by exploding, in this manner, solutions of the alkali earth metals.

II. THE APPARATUS

The apparatus, as used, differed in several minor respects from that described by Anderson. Changes were made with a view to greater convenience and efficiency and are perhaps worth describing briefly.

The condensers were built up of sheets of double strength window glass, $10\times12.5''$, alternating with sheets of roofing tin, $8\times10''$. The tin sheets were pressed and their edges carefully smoothed. Tabs on the corners of the tin sheets projected alternately on either side of the pile and were bolted together. The condensers were built up in piles of sixteen tin plates and firmly tied with cord. Sixteen such piles were constructed. The condensers thus obtained were placed in pairs in large glass battery jars and covered with transil oil. The total capacity thus obtained was of the order of 0.3 M.F. The advantage of such a condenser is that its units are readily portable and easily repaired in case of rupture—no small advantage in the present work since the voltages used were near the rupture voltage of the dielectric and transient surges sometimes resulted disastrously to the glass plates.

The charging voltage was obtained from a 50,000-volt 1-kilowatt transformer. The primary of this transformer was fed with a 110-

[1] *Science*, **54**, 305, 1921.

volt alternating current obtained from the 200-volt alternating current power line of the university by use of a second transformer. The second transformer was employed to protect the university power circuits from the possibility of high frequency transient surges. Rectification was obtained by means of a 100,000-volt 100-milliampere kenotron.

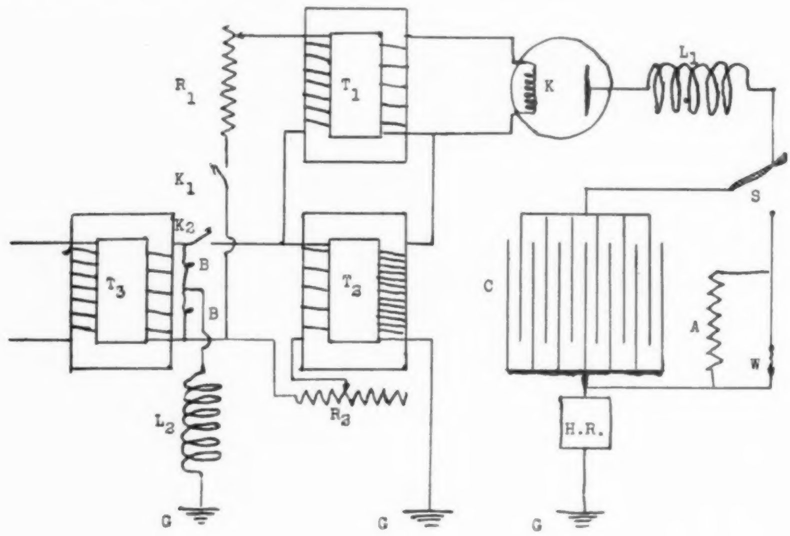

Fig. 1

The discharge circuit was closed by means of a heavy single pole, single throw-knife switch immersed in transil oil. A heavy spring served to close this switch rapidly. It was held open by a trigger device while the condensers were charging. A lever was arranged so that a single pull released the trigger holding the switch open, opened the primary circuit of the high voltage transformer, and opened the high-voltage charging circuit.

The electrical circuit is shown diagrammatically in Figure 1. The features described above will be noted. There is shown, also, a water rheostat which was used to keep down the charging current and protect the kenotron. The water rheostat consisted of a glass tube, about 5 mm bore and 120 cm long. Its resistance was so high that several seconds were required to charge the condensers.

The leak resistance, A, was made from a piece of No. 30 Nichrome wire about 3 m long. It allowed any absorbed charge on the condensers or any charge that did not escape in the first surge across the asbestos fiber to leak off gradually. Its resistance, 65 ohms, was sufficiently high so that only an inappreciable part of the first surge escaped through it.

The inductances, L_1 and L_2, consisted merely of twenty-five turns of wire. They were intended to act as choke coils to stop any high frequency oscillations. To reduce further the possibility of damage by high frequency oscillations a 220-volt carbon lamp, B, was shunted across each half of the secondary of the transformer, T_3, between the ground and the outside terminals.

The fibers were supported on an insulating stand which could be adjusted both vertically and laterally by rack-and-pinion movements. The upper end of the fiber was held in a brass clamp on the stand while the lower end rested against a brass finger.

The spectra were photographed with a 6-foot concave grating, Rowland mounting. The first-order spectrum was used, with a dispersion of 9.4 A per mm. A region of about 700 A could be photographed on the plates employed.

The explosions were focused on the slit with a quartz or glass lens, as the spectral region demanded. The adjustment was made as described by G. A. Hemsalech.[1] A light was placed behind the fiber to illuminate it and the image of the illuminated fiber was focused on the slit by the aid of the vertical and lateral adjustments of the fiber mounting. It is difficult to make this adjustment with great accuracy and so a rather wide slit had to be used. A wide slit was useful also in reducing the number of explosions necessary.

III. PROCEDURE

To take a spectrogram the fiber was saturated with an aqueous solution of some salt of the desired metal; the fiber was focused on the slit as described, the switch S opened, and the high-tension lead attached to it by a spring clip; and the switches K_1 and K_2 closed. A few seconds were allowed for the condensers to charge. The lever was then pulled which simultaneously opened the switch

[1] *Philosophical Magazine*, **40**, 37, 1920.

K_2 and released the trigger on S. As the blade of S descended, the spring clip of the high-tension lead was pulled off. When the switch closed, the charge of the high-tension condenser was discharged through the fiber, with a sharp crack and a brilliant flash. The fiber was uninjured by these discharges and could be moistened and the procedure repeated. From six to twenty such explosions were required, the number varying with the spectral region.

The copper arc was used as a comparison to aid in the identification of the spectra. The copper arc was particularly useful in this work as copper, from the brass clamps that hold the fiber, is the principal impurity in the spectra. The plates were measured on a small comparator and the wave-lengths computed to tenths of angstroms. Greater accuracy was rendered difficult by the character of the lines; because of the width of the slit and because of the high pressure and gaseous velocities in the explosion, the lines were rather broad. The problem, however, was principally one of identification and the accuracy attained was sufficient for that.

IV. DATA

By the use of aqueous solutions of their chlorides, photographs were taken of the spectra of calcium, magnesium, barium, and strontium. The region λ 2280–λ 4550 was completely covered for calcium, while of this range the region λ 3381–λ 3890 for magnesium and barium, and λ 3381–λ 4550 for strontium was not covered.

The chief impurities in the spectrograms are copper and zinc from the brass clamps, as mentioned. There also appeared the strong aluminum pair, λ 3944 and λ 3961, the lead line at λ 4058, carbon at λ 2479, and nitrogen at λ 3995 and λ 4447. A striking fact is that in the spectrum obtained from a salt of any one of the four metals used there always appear many of the strong lines of the other three and of cadmium which is also a member of this group of metals. Although no great effort was made to secure purity of the salts used, the other metals of the group could have been present in the solutions only in very minute quantities. This source seems to be effective in producing spectra of substances which are present in the solution only in extremely low concentrations. It is of interest to note that no lines due to the acid radical employed, chlorine, nor

any lines of hydrogen or oxygen have been identified. If any radiations of these elements were produced, their intensities were too low to register with the exposures used.

The wave-lengths of calcium, magnesium, barium, and strontium, remaining after the elimination of the known impurities,

TABLE I

WAVE-LENGTHS IN EXPLOSION SPECTRA OF THE ALKALI EARTHS

$CaCl_2$		$MgCl_2$		$SrCl_2$		$BaCl_2$		Iden.	True Wave-Length
Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length	Intensity		
2585.8	0	....	.....	....	.....	....	.....	?	
2592.6	0	....	.....	....	.....	....	.....	?	....
2606.5	0	....	.....	....	.....	....	.....	?	....
2612.7	0	....	.....	....	.....	....	.....	?	....
2630.7	1	....	.....	....	.....	....	.....	?	....
2739.3	1	....	.....	....	.....	....	.....	?	....
2756.0	1	2755.7	1	2755.8	1	....	.....	?	....
2790.8	3	2790.8	5	2790.8	5	2790.8	4	Mg	2790.80
2796.5	10	2796.5	12	2796.8	12	2796.7	10	Mg	2795.53
2802.8	8	2802.7	8	2802.6	7	2802.8	6	Mg	2802.69
2852.6	1	2852.2	1	2852.2	1	....	.....	Mg	2852.13
2928.6	2	2928.6	2	2928.6	1	....	.....	Mg	2928.64
2936.9	3	2936.8	2	2936.8	1	....	.....	Mg	2936.76
3107.5	1	....	.....	....	.....	....	.....	?	....
3126.5	1	....	.....	....	.....	....	.....	?	....
3159.0	13	3159.0	6	3159.0	5	....	.....	Ca	3158.88
3180.7	17	3180.8	8	3180.7	7	....	.....	Ca	3181.27
3380.7	8	3381.0	1	3381.0	8	....	.....	Sr	3380.8
3706.1	10	....	.....	....	.....	....	.....	Ca	3706.03
3737.0	12	....	.....	....	.....	....	.....	Ca	3736.91
....	.....	....	.....	....	.....	3891.9	15	Ba	3891.79
3933.7	25	....	.....	....	.....	....	.....	Ca	3933.67
3968.5	20	....	.....	....	.....	....	.....	Ca	3968.48
....	.....	....	.....	....	.....	4078.0	10	Sr	4077.75
....	.....	....	.....	....	.....	4130.7	20	Ba	4130.68
4212.0	2	....	.....	....	.....	4166.0	7	Ba	4166.02
4215.9	1	....	.....	....	.....	....	.....	?	....
....	.....	....	.....	....	.....	4215.6	7	Sr	4215.52
4226.7	3	4227.0	1	....	.....	4226.7	4	Ca	4226.72
....	.....	....	.....	....	.....	4350.4	3	Ba	4350.38
4481.0	7	4481.1	15	....	.....	....	.....	Mg	4481.17
....	.....	....	.....	....	.....	4525.1	7	Ba	4524.95
....	.....	....	.....	....	.....	4554.0	30	Ba	4554.04

are tabulated in Table I. Here are listed for each salt used the wave-lengths obtained, and the intensity, source, and exact wave-length in International Units of each line. It will be noted that there are several unidentified lines, chiefly in the shorter wave-

lengths. It was impossible to identify these lines with the alkali earths or any of the impurities detected. As they may be due to any of a half-dozen or more elements, nothing can be said at this time as to their source.

V. DISCUSSION OF DATA

It will be noted that after the impurity and unidentified lines have been eliminated, strikingly few lines remain. This fact

TABLE II

DOUBLET SERIES OF THE EARTH ALKALIES*

First Subordinate Series $2p_1-md_2$
$2p_1-md_1$
$2p_2-md_2$

Element Ordinal Number	Mg		Ca		Sr		Ba	
	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length	Intensity
3	....	....	....	....	....	....	7485.4	x
	....	....	8498.3	x	10038.3	x	8564.0	x
	2798.0	12	8542.5	x	10328.3	x	or	
	2790.8	5	8662.5	x	10915.0	x	10635.6	x
	....	....	....	....	....	....	10052.4	x
	....	....	....	....	....	....	12084.8	x
4	....	....	3181.4	17	3475.0	x	4166.2	7
	1737.5	x	3179.5	17	3464.6	x	4130.9	20
	1734.7	x	3159.0	13	3380.9	8	3892.0	15
5	....	....	....	....	2324.6	a	2641.5	a
	....	....	2113.0	x	2322.5	a	2634.9	a
	....	....	2103.5	x	2282.3	a	2528.5	a

Second Subordinate Series $2p_1-ms$
$2p_2-ms$

Element Ordinal Number	Mg		Ca		Sr		Ba	
	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length	Intensity
1	2795.5	12	3933.8	25	4077.9	10^c	4554.2	30
	2802.7	8	3968.6	20	4215.7	7^c	4934.2	x
2	2928.6	2	3706.2	10	4161.9	x	4525.2	7
	2936.5	2	3737.1	12	4300.6	x	4900.1	x
3	1753.3	x	2208.9	x	2471.7	a	2771.6	a
	1750.6	x	2198.0	x	2423.7	a	2647.4	a

^{c} = On barium plate.

* These values are taken from Fues, *Annalen der Physik*, **63**, 1, 1920.

becomes even more striking when the lines of the alkali earth metals which do appear are classified according to their series relationships, as is done in Table II. In this table a number in the intensity column opposite a wave-length shows the relative intensity with which the line appeared; an "*a*" indicates that it did not appear on the plate, while an "*x*" indicates that the line lies in a region not photographed in this work. Comparison of the lines in Table II with those in Table I shows that, with one exception in the case of barium, one in calcium, and two in magnesium, all of the lines are members of the first and second subordinate series of the respective metals.

It will be seen that the first two members of each series for each metal appear, if they lie in the region photographed. In the few cases where higher members of the series lie in the region covered, they did not appear on the photograph—probably because of the usual decrease in intensity with increasing ordinal number in series.

Such a spectrum for the alkali earths is of course wholly different from that produced by ordinary laboratory sources. In the usual spark spectrum, members of the triplet and singlet series appear with intensities of the same order as those of the lines of the doublet series. (See for example the tables V and VI of this paper.) Nelthorpe,[1] however, using metallic salts in a discharge tube, obtained results for calcium, barium, and strontium quite similar to these in the region λ 6500–λ 3400.

VI. CORRELATION OF DATA AND THEORY

The explanation of such a spectrum as has been described above is readily found in the modern theories of atomic structure and spectral emission. Bohr has pointed out that, due to quantum changes of one of its outer electrons, a neutral atom will emit a spectrum which is called the "arc" spectrum. An ionized atom, however, has an effective nuclear charge $+2e$ now acting on the outer electron, instead of $+e$ as in the former case, and will consequently emit a totally different spectrum known as the "spark" spectrum.

Sommerfeld[2] has stated in his "Verschiebungssatz" that the "spark" spectrum of any element is similar in series structure to the

[1] *Astrophysical Journal*, **41**, 16, 1915.

[2] Sommerfeld, *Atombau und Spektrallinien*, 3d ed., chap. vi.

"arc" spectrum of elements in the preceding column of the periodic table. He has further pointed out that for the alkali earths the "spark" spectrum consists of the lines of the doublet series, while the triplet and single line series comprise the "arc" spectrum. The "arc" spectrum of the alkalies, then, consists of doublets, while the "spark" spectrum of the alkalies is a complicated spectrum without known series, similar to the spectra of the noble gases. Laboratory evidence in support of the "Verschiebungssatz" has been rather meager. Goldstein,[1] by means of a powerful excitation, succeeded in producing spectra of the alkalies, in which the usual doublet spectra were entirely missing, and which by their complexity, resembled the spectra of the noble gases. It seemed, therefore, that he had not only succeeded in producing the "spark" spectrum of the alkalies, but in doing so had so completely ionized the emitting atoms that the "arc" spectrum was wholly absent. For the alkalies, it was then possible to produce at will either the "arc" or the "spark" spectrum.

The spectra produced in these experiments, it will be seen, then, are almost pure "spark" spectra of the alkali earths. They do for the alkali earths what Goldstein did for the alkalies. They show that it is possible to produce for these metals the "spark spectrum" with practically no trace of the "arc" lines.

It is possible to carry farther the application to the spectra at hand of the quantum theory of emission. In the source under discussion a considerable energy, 50 calories or so, was applied to 1 or 2 milligrams of material. The effect was to heat the material very quickly to an extreme temperature, estimated by Anderson at 20,000° in his case. This heating is so abrupt and its dissipation so rapid that it seems not unreasonable to say that the emission takes place principally, if not entirely, at this high temperature. The reason for thinking this to be the case will be apparent later.

Dr. M. N. Saha in several recent papers has discussed the temperature radiations of gases.[2] Saha's work has been amended

[1] *Verh. d. D. Phys. Ges.*, **10**, 321, 1907.

[2] *Philosophical Magazine*, **41**, 267, 1921, and *Proceedings of the Royal Society* Series A, **99**, 135, 1921.

and extended by Russell[1] and Milne.[2] The conclusions of these writers would seem to be applicable to the explosion spectra. In brief they are as follows (to a large extent Saha's wording is followed).

An atom, cool and unstimulated, has its vibrating electron in the $1s$-orbit. Such an atom or mass of atoms does not emit and can absorb only lines of the principal series, $v = 1s - mp$. If the atoms are heated, the vibrating electron proceeds toward ionization through the various quasi-stationary states and radiation occurs. First we have emission of $1s - 2p$ lines and then of $1s - mp$ or principal series. When the gas emits the line $1s - 2p$ strongly it can absorb the lines of the $2p - md$ and $2p - ms$, diffuse and sharp series. At a higher temperature, the $2p - md$ and $2p - ms$ lines begin to be emitted and the $3d - 4f$ or fundamental series can be absorbed. Thus, as the heating of the atoms continues, the electron proceeds toward ionization, being able progressively to absorb and to emit series corresponding to higher and higher levels of energy.

The theory is not sufficiently developed to permit the calculation of the proportion of atoms in the various quasi-stationary states but the qualitative situation is clear. The temperature at which the fundamental line $1s - 2p$ is emitted and the $2p$-orbits commence to form will be higher, the higher the ionization potential of the element. Other orbits appear at temperatures intermediate between this temperature and the temperature at which ionization is complete. At any state, the proportion of atoms at any energy level will be smaller, the higher the quantum number corresponding to this stage. Thus the $1s - 2p$ and $1s - mp$ series will be the first to appear, the last to disappear, and the most intense always. The $2p - md$, $2p - ms$, and other series will appear later, disappear sooner, and be weaker. The disappearance of $1s - 2p$ marks complete ionization.

After the first step ionization is completed, if heating of the mass of atoms continues, the singly ionized atoms then proceed toward double-ionization through the same cycle of processes described for the un-ionized atoms. The series in question will of course now

[1] *Astrophysical Journal*, **55**, 119, 1922.

[2] *Observatory*, **46**, 261, 1921.

be the series of the "spark" spectrum. As before, the series emitted will afford an index of the energy conditions of the mass of atoms.

Although it is impossible to compute the proportion of atoms in various stages, Saha has pointed out that the proportions of ionized and un-ionized atoms may be computed on the basis of modern thermodynamics by the aid of the Nernst theorem of the reaction-isochore. The equation for computing the percentage of ionization is

$$\log \frac{x^2}{1-x^2} P = -\frac{U}{4.571\, T} + 2.5 \log T - 6.5\,,$$

where x is the fraction of atoms ionized, P, the gaseous pressure, T, the temperature, U, heat of dissociation, or calories to ionize one gram-atom.

Also

$$U = \frac{eVN}{J\,300} = 2.302 \cdot 10^4\, V \text{ calories}\,,$$

where e is charge on the electron, V, ionization potential in volts, J, mechanical equivalent of heat, N, Avogadro's number.

The percentage of ionization is determined by the pressure, temperature, and ionization potential and may readily be computed.

Table III gives for the alkali earths the values of the ionization potential and of the heat of dissociation.

TABLE III

Element	Ionization Potential	U in Calories
Magnesium	7.65	1.761×10^5
Calcium	6.12	1.409×10^5
Strontium	5.7	1.313×10^5
Barium	5.12	1.178×10^5

Table IV gives the values computed by Saha for the percentage of ionization of the alkali earths at a pressure of one atmosphere at various temperatures.

Saha has extended his theory to second-stage ionization also. Corrections to his formulae have been pointed out by Russell and

by Milne (*loc. cit.*). The extent of second-stage ionization, however, need not be considered here since the spectroscopic criteria of such ionization are as yet unknown.

Russell (*loc. cit.*) has shown that if atoms of several kinds are heated together it is possible to compute the fraction of each kind ionized at any temperature and pressure. In general it may be said that if an element is more easily ionized than the average, its percentage of ionization will be greater than if it alone were present. For elements whose ionization potential is greater than the average, the reverse will be the case.

TABLE IV

Temperature of Element	Mg	Ca	Sr	Ba
5000	$5 \cdot 10^{-2}$	2	3.2	5.5
6000	2	8	13	19
7000	6	23	32	43
8000	17	46	58	70
9000	34	70	79	85
10,000	56	85	90	93
11,000	75	93	95	....
12,000	86	96.5	97.5	....
13,000	93	98.5	98.5	....
14,000	96	Complete Ionization		
15,000	98			
16,000	99			

It is now possible, at least qualitatively, to apply the theory discussed above to the spectra under consideration. The solutions used were aqueous solutions of chlorides of the alkali earths. The effect of the explosions was to dissociate these chlorides and the water and to heat the resultant atoms to a high temperature. Since hydrogen, oxygen, and chlorine each have higher ionization potentials than any of the alkali earth metals, the alkali earths were ionized at the expense of these other constituents and to a greater extent than they would have been if the material exploded had consisted of an equal amount of the pure metals. The effect of the explosion is not wholly one of temperature—the electric effects, however, probably act to further the work of the temperature.

The exact temperature and pressure obtained are, of course, unknown. Anderson estimated from the intrinsic brilliancy that the temperature attained was of the order of 20,000° C. From two

different considerations he inferred that the pressure attained from an explosion in a slot in a block of wood was of the order of 20 atmospheres. Since the explosions here discussed took place in the open air, both pressure and temperature were probably somewhat less, although the voltage used, 40,000 volts, was higher than that used by Anderson. It must be remembered, moreover, that in the case of the exploded solutions the pressure to be used in computing the degree of ionization of an element is the partial pressure of that element which is much less, of course, than the total pressure of the explosion. It is probably safe to assume that throughout these experiments, the temperature attained and the partial pressure of the major constituents were in each case of the same order of magnitude. That is, we deal here with spectra of the alkali earths produced all under approximately the same conditions.

Examination of Table IV will show that at a temperature of 15,000° and a pressure of one atmosphere, ionization of each of the alkali earths is practically complete. At higher temperatures or lower pressures the certainty of complete ionization is, of course, greater. These figures are chosen in the belief that they are at least of the right order of magnitude.

Spectroscopic evidence that complete ionization had been attained in these explosions would be the complete suppression of the "arc" spectrum and the appearance of only the "spark" spectrum. As pointed out above, the last arc line to disappear is $1S-2P$; its disappearance indicates complete ionization. For the alkali earths the fundamental line, $1S-2P$, of the single line spectra has the following value for the various elements:

Magnesium	2852.13
Calcium	4226.72
Strontium	4607.34
Barium	5535.69

The line λ 4226.72 is the only calcium line in Table I which is not a member of either the first or second subordinate doublet series. Its intensity, 3, is only one-eighth that of the fundamental doublet pair, λ 3968 and λ 3934. The weakness of λ 4227 and the absence of all other "arc" lines, shows how nearly all radiation takes place from ionized atoms.

In the magnesium spectrum are only two lines which do not appear among the doublets of Table I. One of these lines is the fundamental singlet line, λ 2852, which appears with one-tenth the intensity of the fundamental doublet pair. The other line, λ 4481, is the unresolved first member of the Bergman doublet series, $3d-4f$. Its emission, as pointed out above, denotes the presence of radiating atoms in an even higher energy state than the atoms which emit the sharp and diffuse series.

The lines $1S-mP$ of strontium and barium unfortunately do not lie in the region photographed in this work. However, these lines, if they appeared, would be expected to be relatively fainter even than the corresponding lines of calcium and magnesium (since the heats of dissociation of strontium and of barium are less than those of calcium and magnesium). The appearance of the line, λ 4350, the only barium line, not in the sharp or diffuse doublet series, is puzzling. This has been classed as an "arc" line of barium; that is, its intensity is greater in the ordinary arc than in the spark. It does not seem to have been fitted into any of the known barium series and, therefore, no criterion exists for explaining its appearance.

With the exception of the barium line, λ 4350, the explosion spectra of the alkali earths consist of the fundamental singlet line, $1S-2P$, and of the doublet or "spark" lines. There would seem to be two possible explanations of the persistence of the fundamental "arc" line. First, the pressure and temperature conditions may not be sufficiently extreme to produce complete ionization. In this case it is evident that conditions in the explosion source as here used must be similar to those pointed out by Saha[1] as existing in class A2, A, B9, B8 stars; that is, calcium and magnesium are almost wholly ionized although λ 4227 of calcium still persists. The second possible explanation is that, since we start with our material to be exploded at a normal temperature and the final temperature and pressure cannot be built up instantly, some of the radiation of the neutral atom may appear while the atoms are being brought to their final ionized condition. If so, then, as pointed out above, the lines $1S-2P$ will predominate in the arc spectrum.

[1] *Proc. Roy. Soc.*, A, **99**, 135, 1921.

The effect of electrolytic dissociation, which of course exists in the solution used, somewhat complicates the situation. It is hard to say what effect the electronic rearrangements of dissociation may have on the radiation produced. Some evidence on this point is afforded by some spectrograms taken of the explosions of fine magnesium and calcium wires. The results so obtained are wholly similar to the results with exploded solutions of magnesium and calcium. In general the $1S-2P$ line is not so much weakened

TABLE V

IONIZATION OF MAGNESIUM

Source	Intensity of λ 2795–λ 2803	Intensity of λ 2852	Ratio of Intensities
King's electric furnace	....	1200	....
Crew and McCauley arc	8	10	0.8
Eder and Valenta spark	10	8	1.2
Fowler vacuum arc	50	30	1.7
Exploded wire	10	2	5.0
Exploded solution	10	1	10.0

TABLE VI

IONIZATION OF CALCIUM

Source	Intensity of λ 3933–λ 3968	Intensity of λ 4226	Ratio of Intensities
King's electric furnace	55	1000	.05
Crew and McCauley arc	400	500	.8
Lockyer spark	500	400	1.2
Loving vacuum arc	20	8	2.5
Exploded wire	10	2	5.
Exploded solution	25	3	8.
Chromosphere of sun	72	8	9.
Stars of type B	7	1	7.

in the exploded wire spectra as in the exploded solution. This fact may be due, however, to the lower partial pressure of the metal and the smaller amount of material exploded in the solution; both of these factors would tend toward more complete ionization. The effect of dissociation would then appear to be negligible.

For the purposes of comparison there are given in tables V and VI data on the ratio of the intensities for different sources of the fundamental spark doublet, $1s-2p$, to the fundamental arc singlet $1S-2P$, for calcium and for magnesium. This ratio is, as pointed

out above, an index of the degree of ionization produced in any emitting source. It will be noted that ionization is carried farther in the exploded solution than in the other sources, and that the ionization produced in the exploded solution compares with that in the sun and stars of class B.

In conclusion it may be pointed out that the exploded solution as source, discussed above, must contain a relatively small percentage of un-ionized atoms. Only the fundamental single lines $1S-2P$ and the barium line, λ 4350, appear of the "arc" spectrum and these lines are faint. It, of course, follows from Saha's theory that there must also be slight emission of other arc lines. This emission was, however, too weak to be detected by the means at hand.

Further studies of the spectra produced by this type of discharge are now being carried on.

VII. SUMMARY

1. A modification of Anderson's exploded wire as source of light is developed, in which there is exploded, in place of the wire, an aqueous solution of any salt of the desired metal. The method is thus made applicable to any metal, rather than only to those which can be obtained in the form of fine wires.

2. The application of this source to the alkali earth metals produced for these metals an almost pure "spark" spectrum.

3. The correlation of this data with Sommerfeld's "Verschiebungssatz" and with Saha's theories of the temperature radiation of gases is discussed. The data afford corroboratory evidence for both these theories.

Physical Laboratory
University of Michigan
August 1922

THE EFFECT OF A PROBABLE ELECTRIC FIELD ON THE BANDS OF NITROGEN

By SNEHAMOY DATTA

ABSTRACT

Broadening of nitrogen positive bands in presence of bromine vapor.—The partial pressure of bromine vapor in a discharge tube containing some air was varied by immersing a side tube in different freezing mixtures. With the lowest partial pressure ($-78°$ C.), the bands were sharp, but as the pressure was raised the bands showed evidence of blurring, especially the more refrangible ones, the effect increasing with the pressure until for $-5°$ C. even the heads had disappeared, leaving only diffuse patches where the bands had been. Both the second and third bands showed the effect, and the bands below λ 3900 were absent entirely, though a quartz spectrograph was used. It is suggested that the blurring may be a Stark effect produced by the electric fields of the ionized bromine atoms. Though this effect has not been directly observed in the laboratory, it was predicted by Hettner from theoretical considerations. The similar blurring due to increased pressure in pure nitrogen may also be a Stark effect. However, the *cyanogen band* was unaffected by the bromine.

Suggested explanation of displacement of bands by pressure of foreign gas.—The displacements observed by Dufour and Clinkscales in the case of the bromine and sodium bands may also be a Stark effect due to the electric field of the ionized atoms of the foreign gas, even though the effect has not yet been observed for any bands in the laboratory.

I. INTRODUCTION

It is well known that, beside the characteristic line and band spectra, the majority of elements emit under proper conditions a continuous spectrum, which has not been resolved into fine lines by the highest dispersion used. It has also been definitely proved that some of these continuous spectra—especially those of the halogens—do not belong to the class of radiation emitted by glowing hot bodies. No satisfactory explanation, however, has yet been given. Lately, a possible suggestion has been made by Professor J. Franck,[1] who considers the continuous spectra to be the type of radiation one would expect during the formation of negative ions (atoms+electrons). From the frequency ν_0 of the head of the continuous spectrum, which must be on the less refrangible side, according to his theory, the energy necessary to remove the additional electron from the normal atom (i.e., the electron affinity of the atom) can be calculated. From the data furnished by W. Steubing,[2] Franck has calculated the electron affinity of iodine,

[1] *Zeitschrift für Physik*, **5**, 428, 1921. [2] *Annalen der Physik*, **64**, 673, 1921.

which appears to agree well with the values theoretically deduced by M. Born.[1] Bromine was known to possess a continuous spectrum, and it was thought worth while to investigate whether this could be regarded as its electron affinity spectrum. Work on this subject was at first undertaken in the Physical Institute of Göttingen University under the direction of Professor Franck.

2. EXPERIMENTS

A preliminary investigation was undertaken to determine the exact condition when the continuous spectrum could be obtained at its brightest. The type of discharge tube finally chosen for the purpose was an ordinary Jena glass tube of internal diameter about 1.5 cm, having as the electrodes a platinum point and a plate at a distance of about 2 cm. The discharge chamber was connected by glass tubes with a side reservoir for bromine. By warming the reservoir sufficient vapor was allowed to escape to displace the air in the tube. The tube was then sealed. The pressure in the discharge chamber was conveniently regulated by immersing the side tube in a Dewar flask filled with a pasty mass prepared by mixing solid carbon dioxide with acetone. At about -5° C., the color of the discharge changed from yellow to pink, and the discharge itself became very steady but feeble. This pink discharge emitted the brightest continuous spectrum. The discharge being very feeble, instruments of high dispersion could not be used, and photographs were therefore taken with a quartz spectrograph giving a dispersion of about 32 A per mm at λ 3800.

The continuous spectrum thus obtained, however, did not agree well with the description of the electron affinity spectrum as demanded by the theory. The present investigation, therefore, fails to throw any definite light on the cause of the emission of the continuous spectrum.

In the course of the investigation, however, a peculiarity was observed in the nature of the continuous spectrum. The spectrum, instead of continuously fading away, showed a succession of maxima and minima of intensity, due to the overlapping of strong diffuse patches. The position of the patches suggested that they might

[1] *Zeitschrift für Physik*, **5**, 433, 1921.

have something to do with the second positive bands of nitrogen which occur in this region. Experiments were therefore made to observe the changes (if any) of these patches at various pressures of bromine. It was then found that by immersing the side tube in a bath at -78° C., the discharge chamber looked perfectly white, owing to bromine distilling over and solidifying in the side tubes. The color of the discharge turned into gray and the spectrum (Plate V, Fig. 1*b*) showed the second positive bands of nitrogen prominently, together with a very faint continuous background due to bromine. The spectrum has been compared with that of an ordinary nitrogen tube for identification (Fig. 1*a*). On the continuous ground only one diffuse patch appeared (marked with a black dot and a pair of brackets in Fig. 1*b*), which had no correspondence with the nitrogen spectrum. This was subsequently identified with "the band with ill-defined edges due to bromine," described by Strutt and Fowler[1] in connection with their investigations of the active modification of nitrogen.

On raising the temperature of the bath to -40° C., the color of the discharge tube became slightly yellow, owing to the increase in the quantity of bromine, and the discharge changed from gray to somewhat pink. The spectrum at this stage, showed a marked change in the overlapping nitrogen bands (Fig. 2*b*). Instead of all the heads in each group being fully developed, only the less refrangible head became prominent, and this was followed by a patch of continuous spectrum. All the bands were not equally blurred, and the blurring increased on proceeding to the side of short wavelength. At the same time, some of the stronger nitrogen bands (those beyond λ 3900), which lie outside the continuous spectrum, do not appear at all. Bromine vapor has an absorption band in this region, with the maximum about at λ 4100. But, under the condition of the experiment, when there is so little bromine present in the discharge tube, it was doubtful whether absorption alone could account for the entire absence of these bands. A separate experiment on the absorption of such thin layers of bromine fully supported the doubt. That absorption is not possible, even when the tube is excited, is shown by the presence of a few faint lines of bromine in that region. In the presence of the

[1] *Proceedings of the Royal Society*, A, **86**, 105, 1912.

PLATE V

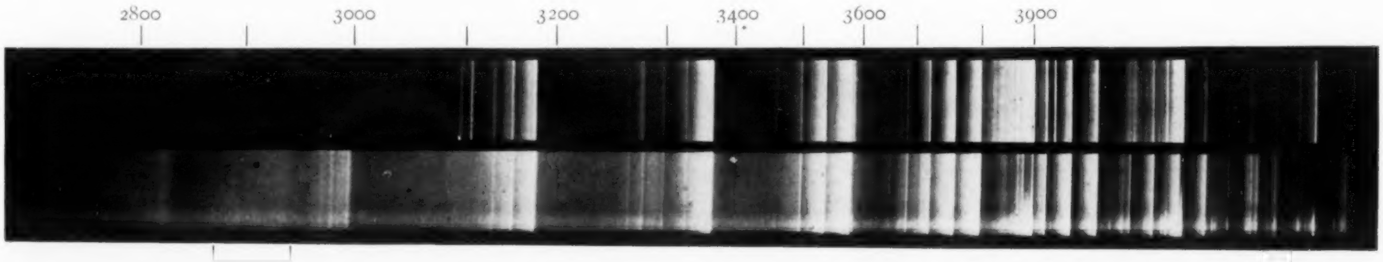

Fig. 1

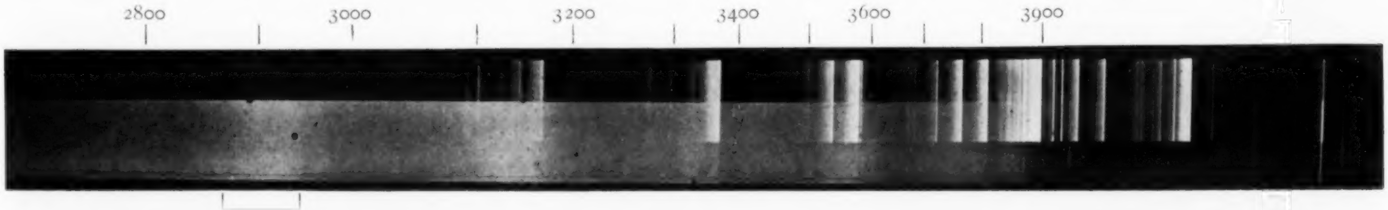

Fig. 2

Fig. 3

continuous emission, it may therefore be said that some groups of the second positive bands are developed in preference to others. A satisfactory explanation cannot be given, but a possible one, in the light of a theory recently developed by the author, will be presented in a subsequent section.

On further raising the temperature to about $-20°$ C., the spectrum showed a perceptible diminution in the sharpness of even the least refrangible head in each group. The density and the diffuseness of the patches also simultaneously increased. (This stage is not shown in Plate V.)

On still further raising the temperature to $-5°$ C., at which the continuous spectrum was obtained brightest, the spectrum showed only diffuse patches (Fig. 3), obtained with an instrument of lower dispersion, the characteristic feature of the nitrogen bands being entirely lost. Raising the temperature above $10°$ C., the continuous spectrum almost vanished, and only the lines of bromine appeared.

The foregoing experiments therefore justify the conclusion that the patches are developed by some sort of interaction between bromine and nitrogen.

The experiments were repeated in the spectroscopic laboratory of the Royal College of Science, London, where, in addition to the second positive bands, the third positive bands were also developed. On admitting bromine vapor into the discharge chamber, the spectrum showed blurring throughout. In view of the fact that both the second and the third positive bands are blurred, it is difficult to consider so many coincidences as representing the ill-defined band spectrum of some chemical compound of bromine and nitrogen. Besides, at such low temperature, reaction between bromine and nitrogen is not known in chemistry. Consequently it may safely be concluded that the bands are independently developed by the condition of discharge in the tube, and these are then blurred by some physical action of bromine.

3. DISCUSSION

Bromine is strongly electro-negative; consequently, during the discharge, owing to its strong tendency to capture an extra electron, it forms a negative ion, so that there is a strong electric field in its neighborhood. It is this electric field of atomic origin

which possibly brings about a resolution and displacement of the nitrogen bands. As the different radiating molecules of nitrogen are at different distances from the bromine atoms, they will be subjected to electric fields of all values. Consequently there will be all degrees of resolution and displacement of the bands, the total effect of which will be to produce a complete blurring of the nitrogen bands. As such blurring depends on the chances that a radiating nitrogen molecule will be in the sphere of electrical action of the bromine atom, it is evident that the blurring would be more probable with the increase in the number of active bromine atoms. The fact that the blurring of the nitrogen bands increases with the intensity of the continuous spectrum suggests that the active bromine atoms are those that are responsible for the radiation of the continuous spectrum. Consequently it may be suggested that the mechanism of radiation of the continuous spectrum of bromine is somehow or other connected with the formation of negatively charged atoms.

The Stark effect has not been observed in the case of band spectra. In all probability, the external electric field applied in the laboratory is much smaller in magnitude than the suggested one of atomic origin. The negative result obtained in the laboratory is therefore not sufficient evidence against the suggestion made in this paper. In addition the conclusion drawn here receives support from the work of Hettner.[1] From theoretical considerations Hettner has shown that molecular rotation must be influenced by an electric field and has suggested that such influences should be looked for in the absorption bands of gases and vapors in the infrared region, these being due to molecular rotations. The recently developed theory of band spectra ascribes the flutings of a band to molecular rotations, their position in the visible region being due to the addition of a second term giving the electronic energy of the system. Consequently the resolutions and displacements of the flutings of the nitrogen bands, resulting in a blurring of the whole system, are in agreement with Hettner's suggestions.

Attention has already been drawn to the fact that, with the emission of the continuous spectrum, some of the bands of nitrogen are not at all developed, and that among those developed the

[1] *Zeitschrift für Physik*, **2**, 4, 349–60, 1920.

blurring increases as one proceeds to the more refrangible region. For this no explanation can be given, but in the light of the theory of band spectra, as recently extended by the author, it is possible to make an attempt at an explanation.

Following the suggestion of Heuelinger and Lenz that the different bands, usually associated in a group, are due to the quantum changes of atomic vibration, it has been shown that such quantum states correspond to the different degrees of dissociated states of the molecule and that radiation takes place in a change from one state to another. A general equation has been arrived at involving two successively varying integers m and n, where m refers to the order number of the final state after radiation and n to the quantum changes in the process of radiation. On arranging the second positive bands of nitrogen into series, the more refrangible bands are found to correspond to the higher values of m, i.e., to the states of higher partial dissociation. In the presence of bromine, owing to its strong affinity for electrons and the resulting electric field, the molecules of nitrogen must be thrown into higher states of dissociation, and consequently the radiation corresponding to low values of m must be missing. This may therefore account for the absence of some of the less refrangible nitrogen bands.

We may similarly account for the increase of blurring in proceeding to the more refrangible region. These more refrangible members, as already pointed out, correspond to high states of partial dissociation. Owing to the swelling of the molecules in such states, they come in closer proximity to the bromine atoms. The electric field acting upon them is thereby increased and a greater blurring takes place.

Further, it may be remarked that the present suggestion, that bands may be displaced and resolved by an electric field of atomic origin, may possibly explain some of the hitherto obscure results as to the influence of a foreign gas on the absorption of certain gases and vapors, some of which may now be mentioned.

Dufour[1] found that the absorption bands of bromine vapor tend to shift toward the red with an admixture of other gases such as hydrogen. Clinkscales,[2] working on the banded absorption of sodium vapor, found that some of the bands shift as much as

[1] *Comptes Rendus*, **145**, 757, 1907. [2] *Physical Review*, **30**, 594, 1910.

0.15 A toward the violet in the presence of hydrogen. Assuming that the effect of the field due to an electro-negative atom is to produce a displacement to the short wave-length, as is to be concluded from the present experiments, hydrogen being electro-positive, the displacement observed by Dufour must be on the red side. At the same time, hydrogen being less electro-positive than sodium, the admixture of hydrogen with sodium produces the same effect as if it were an electro-negative element, and consequently the displacement will be on the violet side, as observed by Clinkscales.

It is also possible to explain why Huddleston,[1] working on "the effect of pressure on the band spectrum of nitrogen," has found that with increase of pressure there is a gradual formation of a continuous spectrum. The increase of pressure brings the molecules into sufficient proximity to produce the necessary electric field, which brings about the resolution and displacement of the bands, causing the flutings to change to continuous bands.

In the light of the experiments described in the present paper, it will be interesting for those possessing the necessary equipment to examine the effect of a very strong electric field on the bands of nitrogen. The CN bands beginning at λ 3883 also appeared in the discharge (see Plate V) and since these were not blurred at any stage of the experiment, the conclusion is that the field due to the neighboring bromine atoms is not sufficient to produce any effect on the radiating cyanogen molecule; it would be interesting to test this with an external field. Iodine and chlorine being also strongly electro-negative, their effect on nitrogen and other gases will be studied at the earliest opportunity.

In conclusion I beg to record my thanks to Professor J. Franck, director of the Physical Institute at Göttingen, for giving me all facilities and for the kind interest he took in the work which was commenced there. My thanks are also due to Professor A. Fowler for kindly allowing me to complete the work here and for the interest he has taken in it all along.

IMPERIAL COLLEGE OF SCIENCE
June 30, 1922

[1] *Physical Review*, **18**, 327, 1921.

A NEW SCOUTING SPECTROSCOPE FOR PROMINENCES

By OLIVER J. LEE

ABSTRACT

Compact rotating spectroscope for detecting and following solar prominences.—This instrument can be readily attached to the 40-inch telescope without removing other apparatus. It is used outside of the cone of rays coming from the large objective and is fed by a plane mirror, suspended by detachable brackets from the base of the spectroscope, which is set at an angle of 45° with the optical axis of the refractor. The combined weight of the two parts is 25 pounds. The instrument accommodates a beam of light 28 mm wide, given by a slit curved to the limb of the sun. The dispersing unit is a plane grating, by Michelson, having 15,000 lines to the inch. *Position angles* of prominences may be read directly. The observer can tell, at once, whether or not an eruption possesses size or detail which should be recorded with the spectroheliograph. The development of a prominence between photographs may be followed. Much time will be saved in periods of little solar activity.

The instrument here described was designed by the writer and constructed by Mr. Stephen Stam in the machine shop of the Yerkes Observatory. Several considerations led to its construction:

1. It takes at least $1\frac{1}{2}$ hours to remove the instrument used the night before on the 40-inch telescope, attach the Rumford spectroheliograph, and take and develop the prominence plates. When, as at present, solar activity is at or near a minimum, almost all of this time is wasted. It is, however, desirable to know when an eruption of any importance is taking place, so that photographic records may be made of it.

2. Such a spectroscope must be light of construction, must be easily attached to the telescope without removing other instruments, and when attached it must not interfere with the use of the spectroheliograph when this is desired.

3. Some means has been wanted for following the development of a prominence without photographing it continuously.

4. Its purpose is reconnaissance and not measurement. Perfection of parts and of adjustment is entirely subsidiary to ease and speed of manipulation.

All of these conditions have been fairly met.

Figure 1 shows the arrangement of the instrument and the path of a ray of light through it.

A pair of reflecting prisms having square surfaces 28×28 mm and collimating and telescope lenses having the same aperture and focal lengths of 28 cm were obtained from John B. McDowell. All these parts were "seconds." The pair of prisms cost $5.00 and the pair of lenses complete with cells $15.00. With these parts and an old straight slit, a working model of wood and paper tubes was

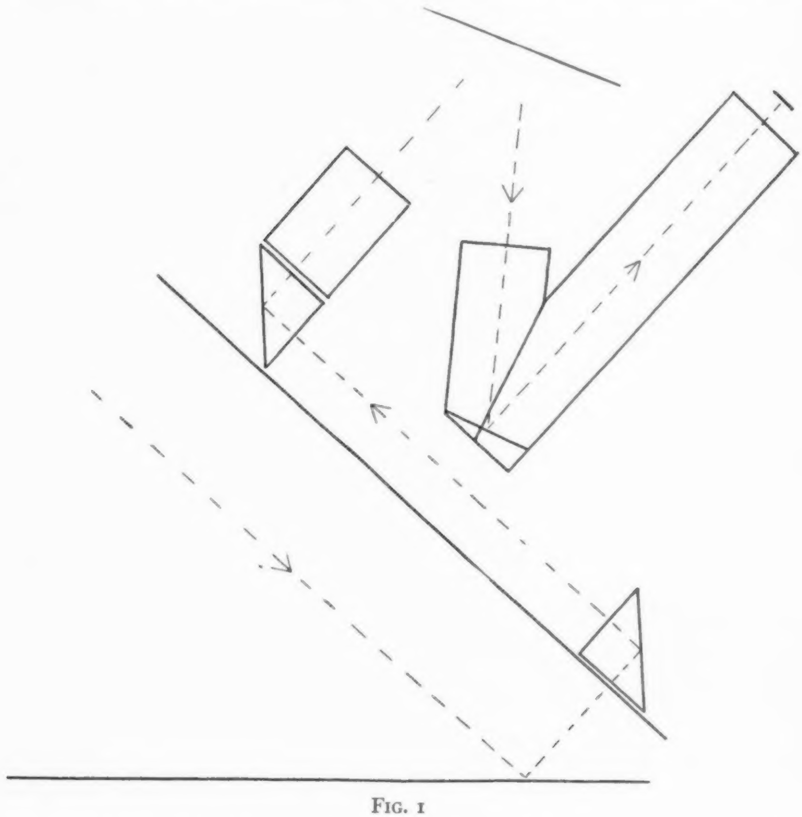

FIG. 1

made, which showed prominences well enough but was too crude to work with. Concrete improvements in construction were almost automatically suggested by this model and the permanent instrument shown in Figure 2 was the result. It is a rotating spectroscope.

It is built on a wooden board $3 \times 32 \times 75$ cm in size. To this board is screwed a pan-shaped aluminum casting, the bottom of

which is a circular piece of steel 4 mm in thickness. This plate rotates freely and forms the base to which are attached the various parts of the spectroscope.

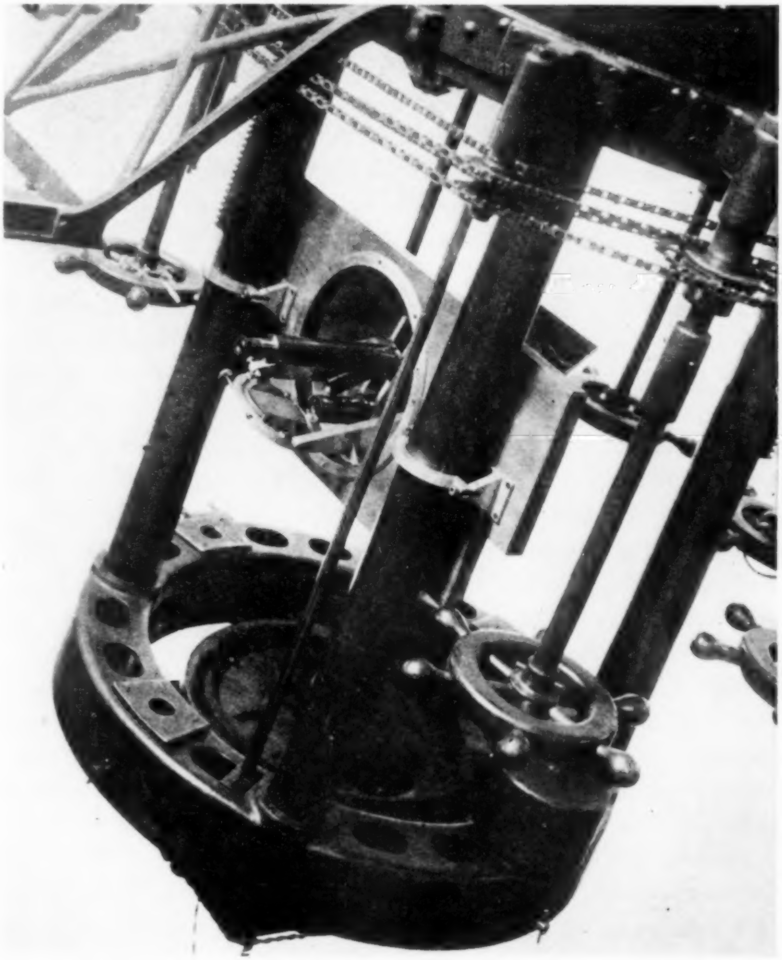

FIG. 2.—Scouting spectroscope for prominences attached to 40-inch telescope

The reflecting device, by which the solar image is turned 90 degrees and is brought to a focus outside of the cone of light of the 40-inch telescope, is separate from the rest. It consists of a mirror of plate glass 20×30 cm in size, which is partly covered by an ellip-

tical metal disk somewhat smaller than the solar image to protect it from that 95 per cent or more of the solar light which is not needed for detecting prominences on the limb. This part of the instrument is attached to the other by setting it upon four half-inch dowel pins, and it is secured in position by two spring clamps which are lifted and turned 90 degrees. The two parts taken together weigh 25 pounds.

The slit is curved to the limb of the sun and moves around it, taking about one linear inch at each step. Besides relative motion of the jaws of the slit, both may be moved together to allow for the slight variation in the apparent size of the sun.

On the observer's side of the instrument the plan of construction is easily seen. Compactness and sufficient lengths of optical path were the two opposing conditions and the compromise in the form of the spectroscope is evident. The dispersing unit is a Michelson grating, already in the possession of this observatory, having 15,000 lines to the inch. It has means of adjustment about the three axes. A spiral groove in the inner tube which carries the collimating lens engages a small set screw in the outer tube and focusing is done by simply turning this inner tube. An eyepiece giving a magnification of about fifteen diameters has been found most serviceable. A circular scale is so attached that position angles, NESW on the sun, of any prominence may be read directly.

Figure 2 shows the spectroscope in place on the 40-inch telescope. The routine of observing is simple. The instrument ring with whatever apparatus is attached to it is racked out, the spectroscope is put in place, the removal of two 15-pound weights establishes "balance," and the solar image is centered. When successive parts of the solar limb are examined, a slight pressure upon the refractor throws the chromosphere upon the slit, which flashes out red along its whole length at once if the C line is centered in the field. A prominence is quickly discovered by showing in the slit before the chromospheric arc centers. Since it takes a fairly strong prominence, visually, to show on a spectroheliogram, there is little danger of overlooking any which would be worth photographing, except, of course, a floating cloud completely detached from the solar limb. If, however, the region above every seat of activity be exam-

ined to some distance from the limb, the chance of even such an omission is almost completely eliminated. The interval of time from the moment the observer enters the dome until the survey is completed is less than 20 minutes and any subsequent examination may be made in 2 minutes.

The construction of a similar spectroscope for other telescopes would, of course, be even more simple if the base of the instrument can be placed in the focal plane of the objective. When the spectroscope can be used directly in the focal plane of the telescope and when there are not so many other conditions to be met in construction and use as existed in the case of the 40-inch telescope, it is possible to employ one of the many forms of instrument which are made by Adam Hilger, Ltd., London, for visual observation of the solar prominences.

Yerkes Observatory
October 2, 1922

REVIEWS

The Origin of Spectra. By PAUL D. FOOTE and F. L. MOHLER, Bureau of Standards, Washington, D.C. New York: Chemical Catalog Co., 1922. 8vo, pp. 249.

The applications of spectroscopy to the problem of atomic structure have given great stimulus to the study of spectra and to attempts to correlate spectral phenomena with phenomena in all fields which bear on the subject of atomic structure. The developments have been so rapid and varied that there has been great need of a critical, comprehensive, and suggestive survey of this field. This need has been admirably met by Dr. Foote and Dr. Mohler in their *Origin of Spectra.* This book may be considered as a supplement to Sommerfeld's *Atombau und Spektrallinien,* in that it starts with the general concepts which have been set forth by Bohr and Sommerfeld, and presents clearly the large variety of tests, interpretations, and consequences of these concepts. The subject-matter deals largely with experimental results and methods, but always with clear exposition of the theoretical and interpretative bearing of these results.

Chapters i and ii review the Bohr theory of spectra, with Sommerfeld's theory of fine structure and of the origin of the various types of spectral series in arc, spark, and X-ray spectra. Particularly useful is the critical discussion of the two prevalent systems of series notation, Fowler's and Paschen's, and the discussion of "energy diagrams," with examples.

Chapter iii deals with the ionization and resonance potentials of the elements, a subject of great value in interpretation of spectra, and one to which the authors have made contributions of great importance.

Chapters iv and v discuss the nature and peculiarities of absorption and emission spectra, the explanation of these peculiarities and their bearing on the problem of atomic structure, and the mechanism of radiation.

Chapter vi deals with "cumulative ionization," those properties of gases which result from the existence of atoms in excited or metastable states, and the passage of resonance radiation through a gas. The standpoint of "quantized energy of radiation" is boldly assumed, because it is the only standpoint from which the phenomena have been treated

with any success, and also because there is theoretical justification for quantizing energy in the case of harmonic oscillators and, therefore, in the case of special emission.

Chapter vii applies thermodynamical methods, developed by Nernst, Tolman, and others, to the problem of ionization at high temperatures, ionization being treated as a dissociation, as was suggested by Saha. Single and multiple ionization, and evidence from experiments and from solar and stellar spectra are discussed.

Chapter viii discusses thermochemical relations in cycles in which ionization is one step. If the energy changes in all other steps of the cycle are known, the work of ionization may be computed. This method is applied to distinguish between different possible ionization processes in the halogen acids.

Chapters ix, x, and xi deal, respectively, with X-ray spectra, photoelectric effects in vapors, and determinations of Planck's constant h.

Appendix I gives computational data, convenient tables of constants, and ionic or molecular velocities. Appendix II gives a clear account of the principles and results of Bohr's latest work on atomic structure—work which has not yet been published in English.

The book is well printed, unusually free from errors, contains numerous references to original sources, and is thoroughly up to date. It should be of great value to the special student of spectroscopy and related subjects as well as of interest to the reader with general scientific interest.

K. T. Compton

Princeton University

In sorrow we announce the death, on February 6, 1923, of

EDWARD EMERSON BARNARD

Senior Astronomer at the Yerkes Observatory

His valuable counsel, based upon his remarkable knowledge in the many fields of observational astronomy, was always available to the Editors, who gratefully make acknowledgment of their indebtedness to him. His contributions have especially enriched these pages.

An extended biographical sketch will appear in a future issue.